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A STUDY OF HAZARDOUS WASTE MATERIALS, HAZARDOUS EFFECTS AND DISPOSAL METHODS

VOLUME III

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Volume III of this three-volume inventory of hazardous wastes in the United States covers Standard Industrial Classification numbers 29, 31, 311, 32, 329, 33, 331, 333, 34, 347, 80, and 806. Among the information given for these industries are economic statistics; waste characteristics; disposal practices and hazard effects of wastes; industry description; industry growth patterns and production trends; standard production processes; number, size, and geographical location of establishments; description of metal finishing processes; and impact of wastes on water quality. The handling of radioactive waste by the Atomic Energy Commission, waste management by the Department of Defense, and the power utilities are discussed. Lists and ratings of hazardous materials are given.

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Volume III

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The study reported here in three volumes was designed to present background information on hazardous materials for the report to Congress on "National Disposal Study Sites." All persons involved in disposing of or concerned with hazardous wastes will find these volumes of interest.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

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SIC 29—PETROLEUM REFINING AND RELATED INDUSTRIES

1. ECONOMIC STATISTICS

According to the American Petroleum Institute (Reference 5), world petroleum production in 1968 was 14,000 million barrels. U.S. consumption was 4,900 million barrels, broken down as follows:

	Million Barrels	U.S. Consumption (%)
Transportation	2,700	54.6
Household & Commercial	1,150	20.4
Electric Utilities (SIC 4911)	188	3.8
Food & Kindred Products (SIC 20)	30	
Paper & Allied Products (SIC 26)	35	
Chemicals & Allied Products (SIC 28)	302	
Petrol Refine & Related Products (SIC 29)	264	
Stove Clay Glass & Concrete (SIC 32)	14	10.3 (fuel)
Primary Metal (SIC 33)	59	
All Mineral & Other Mfg. Industries	117	10.2 (nonfuel)
Miscellaneous	53	
Approximately	4,900	100%

The principal raw material use of petroleum is as a base input or feedstock for the production of petrochemicals. The growth rate in petroleum feed stocks has been approximately 10 percent annually between 1964 and 1968. In 1968, approximately 66 percent of the non-energy petroleum products was consumed in the industrial sector for making petrochemicals, in aluminum manufacturing (electrodes), as lubricants and waxes, and other purposes: 29 percent was used in the commercial sector in the form of asphalt and road oil, and 5 percent consumed as lubricants in the transportation sector.

Intermediates produced from petroleum (including natural gases) are used in the synthesis of a wide variety of organic chemicals. Such intermediates include ethylene, acetylene, propylene, butylene, ethane, benzene, naptha, toluene, and xylene. Other major petrochemical products are ammonia, synthetic rubber, plastic, resin, and synthetic fiber.

The production of petroleum involves the production of brine or formation water. On the average, two to three barrels of water are produced for each barrel of oil. These oilfield brines cannot be discharged into streams without damaging vegetation, fish, and wildlife. These brines are usually disposed of by returning them to the producing formation or to a comparable underground brine formation. In some cases, brines are used to "force out" oil which remains in the formation. The intrusion of brine from such formations into underground fresh water strata must be considered at all times.

Refineries as well as oilfields process a huge amount of water, i.e., about 7 gallons of cooling water for each gallon of gasoline or other product. Such water becomes polluted with oil or by-products of production and is a pollution hazard if not cooled and treated (purified). Recirculation of cooling water and treatment improvement as well as the use of brackish water are becoming common practices within the industry.

Refinery and petrochemical wastes are a more serious problem, as most of the various chemicals and wastes produced are toxic to aquatic life. Progress has been made in controlling wastes and in improving water quality by use of biological processes, oxidation ponds, trickling filters, and activated sludge processes. Since refineries process oils with significant sulfur content, use fluidized catalysts, and operate various combustion and distillation processes, they emit air pollutants as well as water pollutants. With technological advances, new chemicals, new materials, and new fuels will increase the number of potential pollutants.

At present, industry uses approximately 1,000 million barrels of petroleum annually. Projections vary widely, from 1,500 to 5,000 barrels annually by the year 2000.

The ratios provided by the 1967 Census of Manufactures, indicates a relatively high degree of ownership concentration.

SIC		Percent Ownership by: 4 largest	8 largest	20 largest	50 largest
2911	Petroleum refining	33	57	84	96
2951	Paving mixtures and blocks	14	22	35	51
2952	Asphalt felts and coatings	38	65	86	97
2992	Lubricating oils—greases	38	50	68	84
2999	Petroleum and coal products	82	92	99	100

These concentration ratios are comparable with, but lower than, those in SIC 28, Chemicals and Allied Products.

Petroleum refining is a major producer of products normally classified under other SIC codes. For example, in 1967 the petroleum refining industry produced the following:

Class of Products	Product Code	Value ($ Millions)
Cyclic Intermediates and Crudes	2815	60.5
Industrial Organic Chemicals	2818	129.8
Industrial Inorganic Chemicals	2819	39.2
Plastic Materials and Resins	2821	53.7
Surface-Active Agents	2843	15.6

The geographic distribution of the industry is shown below by establishments with 20 or more employees.

Division	Petrol. Refining	Paving Mixtures	Asphalt	Lube Oils	Petrol. Prod. Nec.
New England	2	11	6	3	
Middle Atlantic	30	33	21	34	
East North Central	45	36	33	36	7
West North Central	22	6	9	15	2
South Atlantic	11	19	15	5	2
East South Central	13	11	8	-	
West South Central	102	13	26	5	2
Mountain	26	10	3	-	
Pacific	38	16	17	11	

Such data indicates an industry which is characterized by a relatively limited number of establishments which are rather uniformly distributed throughout the nation.

2. WASTE CHARACTERISTICS

Hazardous wastes produced within this industry are divided into two general categories: (1) petroleum refinery wastes, and (2) wastes resulting from the production of organic chemicals by integrated refinery-production complexes. The wastes from larger integrated facilities are a combination of typical refinery wastes plus those wastes peculiar to the production of organic chemicals.

(1) Refinery Wastes

The typical production unit in this industry is a larger plant which processes from 50,000 to 400,000 barrels per day of crude oil. This basic starting material is augmented, particularly in the case of petrochemical production, by large amounts of natural gases. Large amounts of sulfuric acid and caustic soda are also used by all plants, roughly a ton of acid and one-eighth ton of caustic for each two barrels of crude which is processed.

Typical liquid wastes that are common to almost all refinery operations can be divided into four categories:

- Spent Caustic Solutions—Result from neutralization of acidic materials in crude oil acidic reaction products formed during thermal or catalytic cracking or during chemical treatment processes. These solutions contain:
  - Sulfides
  - Mercaptides
  - Sulfonates
  - Phenolates
  - Napthenates
  - Other similar organic and inorganic compounds.
- Spent Sulfuric Acid Products—Result from use of sulfuric acid as a treating agent and as a catalyst. These products contain varying compositions of:
  - Acid sludges
  - Black acid.

  The hydrocarbon content may vary from 2 to 60 percent while the acidity can vary from 20 to 90 percent. A variety of organic materials may be contained in these waste streams.

- Foul or Sour Waters—Result from various processing operations, and contain:
  - Sulfides, generally hydrogen sulfide
  - Ammonia
  - Mercaptans
  - Phenolics
  - Organic acids
  - Nitrogen bases
  - Cyanides.
- Miscellaneous Wastes—Include a variety of compounds such as:
  - Sulfonic acids and sulfonates
  - Pyridine and quinoline
  - Cyanides (if high nitrogen oils are processed)
  - Aluminim chloride
  - Phosphoric acid
  - Hydroflouric acid
  - Spent catalysts.

The hazardous material wastes which may be generated within these plants are dependent on the processes used, the care exercised in recovering, recycling, eliminating leakage, and the completeness with which such materials are removed from effluent streams. Although improvements will be made in the recycling and recovery of former wastes, the industry will continue to be faced with difficult disposal problems at the production sites or, should spills occur, while products are in transit to consumers.

The emissions of hazardous materials from refineries may be in the form of air contaminants, water pollutants, or solid wastes. The air contaminants include:

- Oxides of sulfur
- Hydrocarbons
- Carbon monoxide
- Oxides of nitrogen
- Particulate matter
- Odorous (H_2S and mercaptans).

It is estimated that the loss of hydrocarbons from refineries as petrochemical plants varies from 0.1 to 6 percent of the plant throughput, a substantial amount of which may be air emissions (Reference 1).

Solid refinery wastes include (1) inert dry solids such as trash and spent catalysts; (2) combustible solids such as trash and scrap lumber; (3) sludges containing oil, such as spent clays; and (4) sludges containing oil, water, and solids, such as tank bottoms and oil-water separator bottoms.

The disposal of solid wastes is becoming increasingly difficult. Land disposal of solids by dumping or ponding has been common in the past. However, adequate land disposal areas are becoming limited, frequently caused from saturation of available areas or expansion of production facilities. Increasing emphasis on public relations may require elimination of unsightly or odorous dumps or ponds. Air and water regulations also restrict dumping or ponding. Ultimately regulations or public relations may require that wastes discarded in dumps or ponds be removed or disposed of onsite.

(2) Petrochemical Wastes

The products which can be produced from crude feed stocks, whether petroleum crude or natural gases, is infinite. The number of products produced in commercial quantities runs into the thousands. The wastes that may be produced at any one time in a particular plant will vary, based on the particular products being processed and the process used.

Typical waste products which may be produced by various processes and operations (Reference 2) are shown in Table A-6-1.

Table A-6-1

Waste Waters from Selected Petrochemical Processes

Process and Operation	Expected Waste and Effect on Water
Aldehydes and alcohols via the OXO Process	Since crude alcohol mixtures are purified and fractionated by conventional facilities, still slops probably contain some soluble hydrocarbons and traces of aldehydes
Hydrogen cyanide from natural gas and ammonia	Water slops from steam stripping of hydrogen cyanide may contain some hydrogen cyanide and soluble unreacted hydrocarbons
Chlorination of methane and ethylene	Contaminated wastewater, apparently containing oil
Acetylene via cracking of hydrocarbons	Probably minor amount of wastewater containing soluble hydrocarbons
Ethylene and propylene via thermal cracking	Probably some wastewater containing soluble hydrocarbons
Polymerization and alkylation processes	Wastewater may contain caustic soda, hydrocarbons including benzene derivatives, and some catalyst such as phosphoric acid or aluminum chloride
Alcohols from olefins via sulfates and hydrolysis	Probably substantial amounts of wastewater containing sodium sulfate, polymerized hydrocarbons, and alcohols
Ethylene and propylene oxide and glycols from ethylene and ethylene oxide and propylene	Possibly substantial amounts of wastewater containing calcium chloride, spent lime, polymerized hydrocarbons, ethylene oxide, thylene dichloride, glycols
Ketones via dehydrogenation of alcohols (production of acetone and methyl ethyl ketone)	Probably distillation slops containing hydrocarbon polymners, chlorinated hydrocarbons, glycerol, sodium chloride

Table A-6-1 (Continued)

Process and Operation	Expected Waste and Effect on Water
Aldehydes and alcohols by hydrocarbon oxidation	Organic acids, formaldehyde, acetaldehyde, acetone, menthanol, higher alcohols
Butylenes and butadiene from butane and butylene	Amount of wastewater probably small, but containing soluble hydrocarbons
Aromatics via catalytic reforming	Condensate water may contain catalyst, aromatic hydrocarbons, hydrogen sulfide and ammonia
Boiler water treating and corrosion control	Alkaline waste, lime solids, color
Ammonia production	Alkaline wastes
Conversion of nitrogen via catalytic processing	Alkaline wastes
Cracking operations	Acidic wastes
Distillation of intermediate	Acidic wastes
Specialty processes	Usually high in BOD and COD
Naphtha treating	High toxicity
Acid recovery	Color, pH
Cleaning	Color, BOD, toxicity, solids, etc.

The effluent streams from petrochemical plants may contain varying amounts of raw material, reactants, intermediates, end products, and non-hydrocarbon pollutants. The liquid wastes may contain water emulsions, soluble organics, dissolved inorganics, suspended tars and coke, spent caustic, acids and acid sludges, spent filter aids, spent catalysts, spent lime, solvents, and absorbents. Noxious materials such as sulfides and mercaptans may be in the caustic streams; chromates, algicides, phosphates, etc., may be in the process and cooling water waste streams; furfural, monoethanolamine phenols, etc., may be found in the solvent waste streams; and oil and grease may be in all streams from the quench operations. Unfortunately, many processes give rise to hot waste streams and generally the heat is also a pollutant.

A complete listing of all the chemicals in all petrochemical waste streams would be impossible, but a rough grouping according to chemical structure indicates the magnitude of the problem. Table A-6-2 has been prepared by the American Petroleum Institute as a guide. The groupings are according to structure and not on relative effect on water use.

Types of waste products which may result from organic and inorganic compounds (Reference 3) are shown in Figures A-6-1 and A-6-2.

TABLE A-6-2
Classification of Compounds and Waste

Organic Acids and Their Salts
Acetic Acid
Cuprous Ammonium Acetate
Formic Acid

Alcohols
Allyl Alcohol
Ethyl Alcohol
Glycols
Isopropyl Alcohol
Isobutyl Alcohol
Methanol
Octyl Alcohol

Aldehydes and Ketones
Acetaldehyde
Acetone
Aerolein
Formaldehyde
Keytones
Octyl Aldehyde

Amines and Amides
Monoethanolamine
Diethylformamide

Esters
Ethylene Diacetate
Methanol Formate
Amyl Acetate

Ethers
Diethyl Ether
Isopropyl Ether

Hydrocarbons
A. Saturated Hydrocarbons
  Waste Components of Gasolines

B. Unsaturated Hydrocarbons
  Butadiene
  Cracked Napthas
  Divinyl Acetylene
  Methyl Acetylene

C. Aromatic Hydrocarbons
  Aromatic Distillates
  Benzene
  C_6 Aromatics
  Dowtheim
  Diphenyl Oxides
  Naphthene
  Xylene

D. Halogenated Hydrocarbon
  Alkyl Chloride
  Carbon Tetrachloride
  Chlorinated Hydrocarbons (Long Chain)
  Chloroform
  Dichloropropane
  Ethyl Chloride
  Ethylidene Chloride
  Methyl Chloride
  Methylene Chloride
  Propylene Dichloride

E. Polymers
  Olefinic Polymer
  Polychloroethane
  Solid Polychloroethane
  Polyisobutylene
  Rubbers

Phenolic Compounds
Cresol
Phenol

Soaps and Detergents
Detergents
Petroleum Sulfonates
Soaps
Sulfurized Terpenes

Miscellaneous
Dowtherm (see Aromatic Hydrocarbons)
Flux Oil
Mercaptans
Naphthas
Resins
Soot
Tar

Inorganic
Aluminum Chloride
Ammonia
Ammonium Nitrate
Barium Hydroxide
Calcium Hydroxide
Carbon Bisulfide
Chlorine
Chromates
Chromic Oxide Catalyst
Coke
Copper Chloride
Cyanides
Chromium Oxides
Ferrous Dichloride
Hydrochloric Acid
Hydrogen Cyanide
Hydrogen Sulfide
Lime (see Calcium Hydroxide)
Nitric Acid
Phosphoric Acid Catalyst
Potassium Permanganate
Sodium Chloride
Sodium Hydroxide
Sodium Sulfide
Sulfur Dioxide (Sulfurous Acid)
Sulfuric Acid
Sulphates
Waste Caustic Sodas

FIGURE A-6-1
Classification of Organic Compounds Which May Occur in Petrochemical Wastestreams

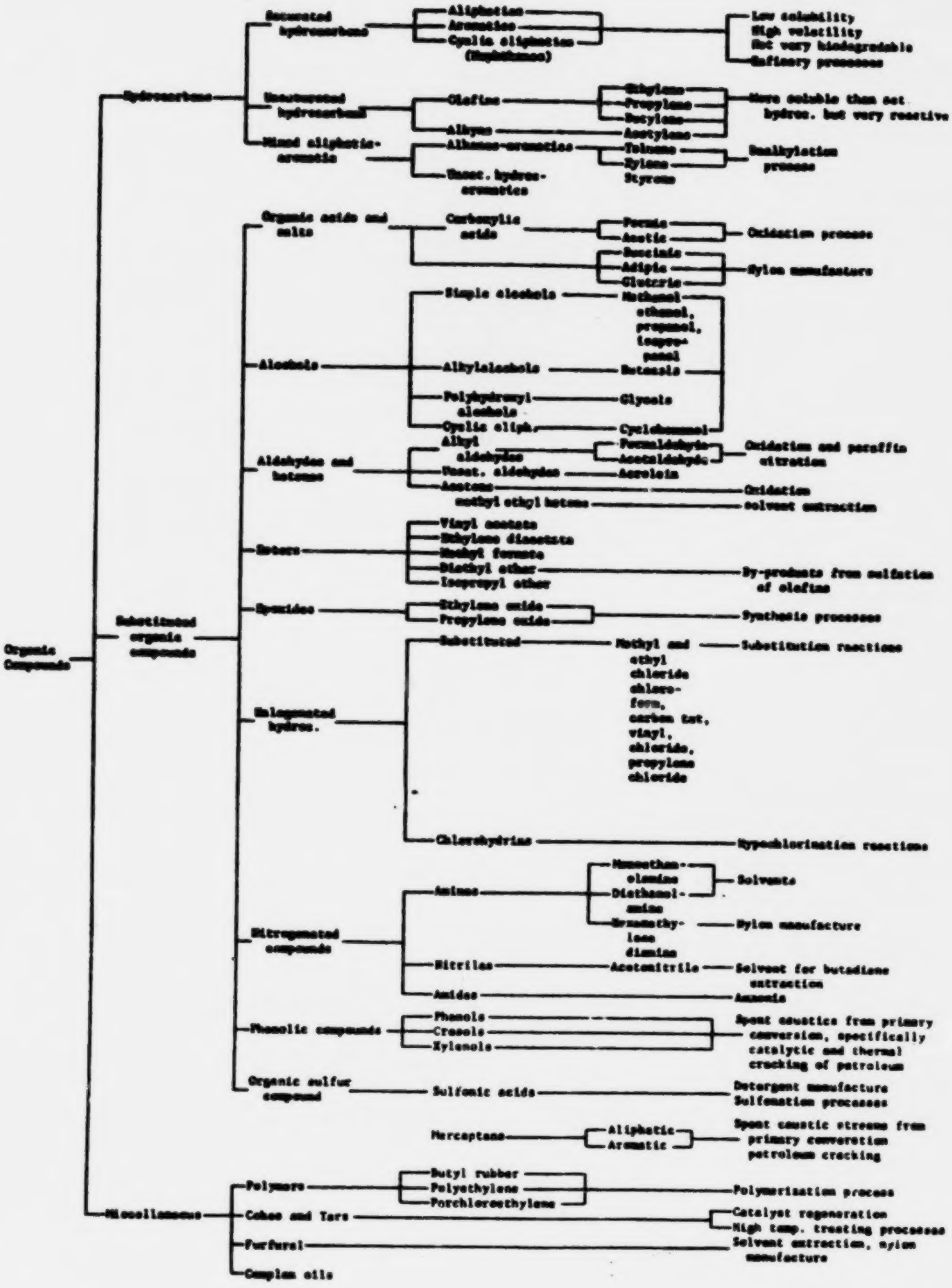
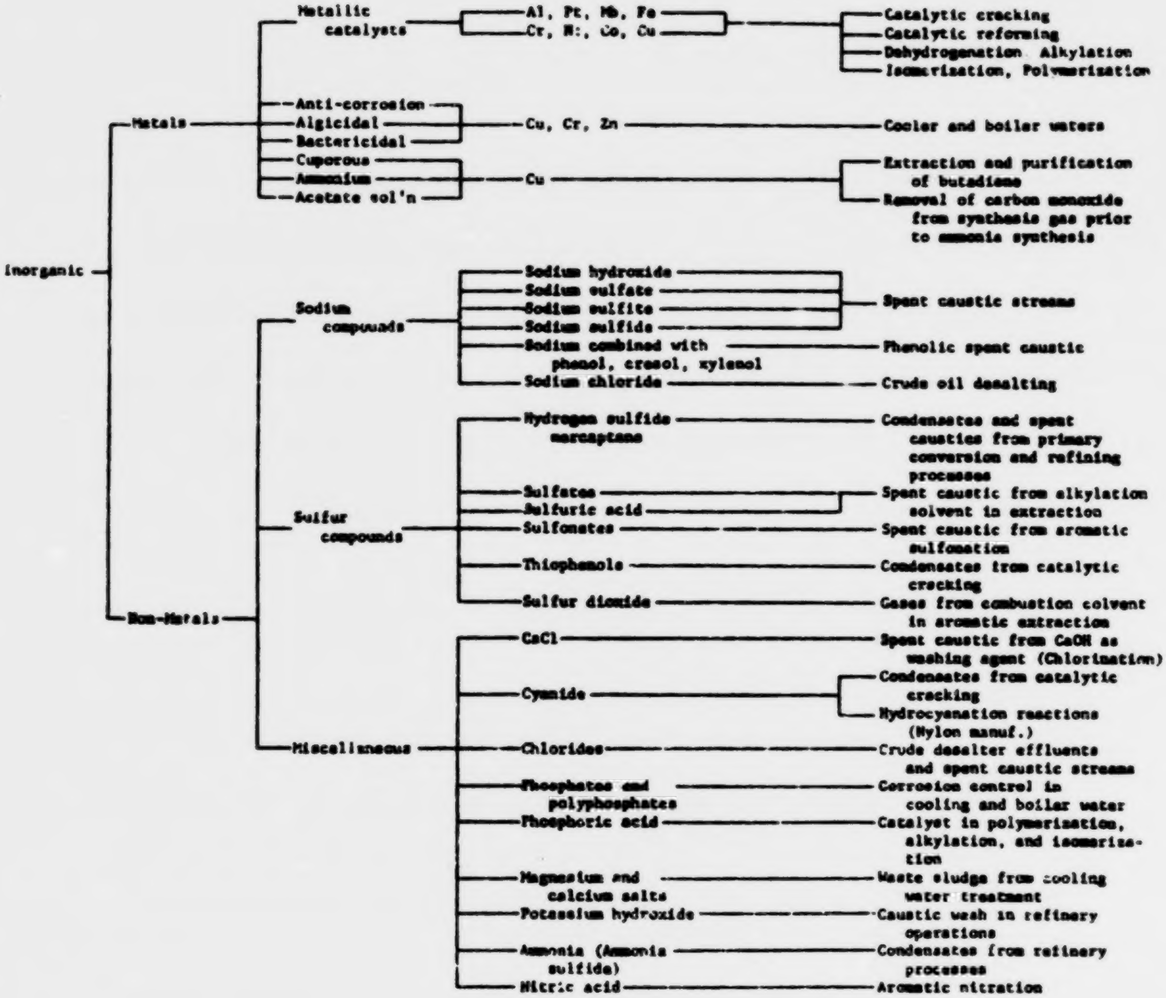

Organic Compounds
Hydrocarbons
Saturated hydrocarbons
Aliphatics
Aromatics
Cyclic aliphatics (Naphthenes)
Low solubility
High volatility
Not very biodegradable
Refinery processes
Unsaturated hydrocarbons
Olefins
Ethylene
Propylene
Butylene
Alkynes
Acetylene
More soluble than sat. hydros. but very reactive
Mixed aliphatic-aromatic
Alkanes-aromatics
Toluene
Xylene
Styrene
Unsat. hydro-aromatics
Dealkylation process
Substituted organic compounds
Organic acids and salts
Carboxylic acids
Formic
Acetic
Oxidation process
Succinic
Adipic
Glutaric
Nylon manufacture
Alcohols
Simple alcohols
Methanol ethanol, propanol, isopropanol
Alkylalcohols
Butanols
Polyhydroxyl alcohols
Glycols
Cyclic aliph.
Cyclohexanol
Aldehydes and ketones
Alkyl aldehydes
Formaldehyde
Acetaldehyde
Oxidation and paraffin nitration
Unsat. aldehydes
Acrolein
Acetone
methyl ethyl ketone
Oxidation
solvent extraction
Esters
Vinyl acetate
Ethylene diacetate
Methyl formate
Diethyl ether
Isopropyl ether
By-products from sulfation of olefins
Epoxides
Ethylene oxide
Propylene oxide
Synthesis processes
Halogenated hydros.
Substituted
Methyl and ethyl chloride chloroform, carbon tet, vinyl, chloride, propylene chloride
Substitution reactions
Chlorohydrins
Hypochlorination reactions
Nitrogenated compounds
Amines
Monoethanolamine
Diethanolamine
Solvents
Hexamethylene diamine
Nylon manufacture
Nitriles
Acetonitrile
Solvent for butadiene extraction
Amides
Ammonia
Phenolic compounds
Phenols
Cresols
Xylenols
Spent caustics from primary conversion, specifically catalytic and thermal cracking of petroleum
Organic sulfur compound
Sulfonic acids
Detergent manufacture
Sulfonation processes
Mercaptans
Aliphatic
Aromatic
Spent caustic streams from primary conversion petroleum cracking
Miscellaneous
Polymers
Butyl rubber
Polyethylene
Perchloroethylene
Polymerization process
Cokes and Tars
Catalyst regeneration
High temp. treating processes
Furfural
Solvent extraction, nylon manufacture
Complex oils

FIGURE A-6-2
Classification of Inorganic Compounds Which May Occur in Petrochemical Wastestreams


Inorganic
Metals
Metallic catalysts
Al, Pt, Mb, Fe
Cr, Ni, Co, Cu
Catalytic cracking
Catalytic reforming
Dehydrogenation Alkylation
Isomerization, Polymerization
Anti-corrosion
Algicidal
Bactericidal
Cu, Cr, Zn
Cooler and boiler waters
Cuporous
Ammonium
Acetate sol'n
Cu
Extraction and purification of butadiene
Removal of carbon monoxide from synthesis gas prior to ammonia synthesis
Non-Metals
Sodium compounds
Sodium hydroxide
Sodium sulfate
Sodium sulfite
Sodium sulfide
Spent caustic streams
Sodium combined with phenol, cresol, xylenol
Phenolic spent caustic
Sodium chloride
Crude oil desalting
Sulfur compounds
Hydrogen sulfide mercaptans
Condensates and spent caustics from primary conversion and refining processes
Sulfates
Sulfuric acid
Spent caustic from alkylation solvent in extraction
Sulfonates
Spent caustic from aromatic sulfonation
Thiophenols
Condensates from catalytic cracking
Sulfur dioxide
Gases from combustion colvent in aromatic extraction
Miscellaneous
CaCl
Spent caustic from CaOH as washing agent (Chlorination)
Cyanide
Condensates from catalytic cracking
Hydrocyanation reactions (Nylon manuf.)
Chlorides
Crude desalter effluents and spent caustic streams
Phosphates and polyphosphates
Corrosion control in cooling and boiler water
Phosphoric acid
Catalyst in polymerization, alkylation, and isomerization
Magnesium and calcium salts
Waste sludge from cooling water treatment
Potassium hydroxide
Caustic wash in refinery operations
Ammonia (Ammonia sulfide)
Condensates from refinery processes
Nitric acid
Aromatic nitration

3. DISPOSAL PRACTICES

Petrochemical and refinery waste disposal practices can be grouped into four general methods of treatment:

- Reduction of in-process wastes
- Physical treatment processes
- Chemical treatment processes
- Biological treatment processes
- Ultimate disposal techniques

Recent legislation requiring the elimination of all waste emissions into air and water will place increased emphasis on the first category of treatment methods. The ideal method of controlling wastes is to eliminate them at the source. The recovery of usable by-products goes hand-in-hand with the elimination of losses from leaks, spills or evaporation.

The reduction of in-process wastes includes:

- Reduction of raw material losses through elimination of leaks from storage, transport, and processing facilities
- Recovery of usable reaction products through recycling, conversion, or sale
- Process modifications to include new processes and improved operating methods
- Water reuse to reduce the quantities of diluted waste
- In-plant controls to continuously monitor for leakage or operational malpractices.

Physical treatment processes include:

- Gravity separation
- Stripping processes
- Solvent extraction
- Absorption
- Combustion
- Filtration
- Evaporation
- Spraying.

Chemical treatment processes include:

- Neutralization and pH adjustment
- Coagulation and precipitation
- Oxidation
- Ion exchange
- Reduction.

Biological treatments processes include:

- Activated sludge
- Trickling filters
- Aerated lagoons
- Waste stabilization ponds.

Ultimate disposal techniques include:

- Incineration
- Deep-well injection
- Dumping at sea
- Approved landfill operations.

Figure A-6-3 illustrates various applications of these techniques in reducing refinery pollutants (Reference 4). A list of inplant control and treatment processes for the petroleum refining industry is presented in Table A-6-3. Another evaluation of the relative efficiencies of such treatments (Reference 4) are shown in Table A-6-4.

These tables indicate the variation in possible waste treatment and give some indication as to the residual contamination which is to be expected after wastes are treated. Complete elimination of all contamination from air and water will require substantial extention of the most advanced techniques throughout the industry.

The American Petroleum Institute's Manual on Disposal of Refinery Wastes (Reference 5) contains process summaries for handling specific wastes.

Present treatment processes do not remove all toxic materials from the waste streams prior to their discharge into the water or into the air. If water flows are sufficiently large, or if large bodies of water are available in which to dilute the effluents, the toxic substances in the residual waste streams may be sufficiently diluted by

APPENDIX A-6-19

FIGURE A-6-3

Sequence/Substitution Diagram of Waste Treatment Processes

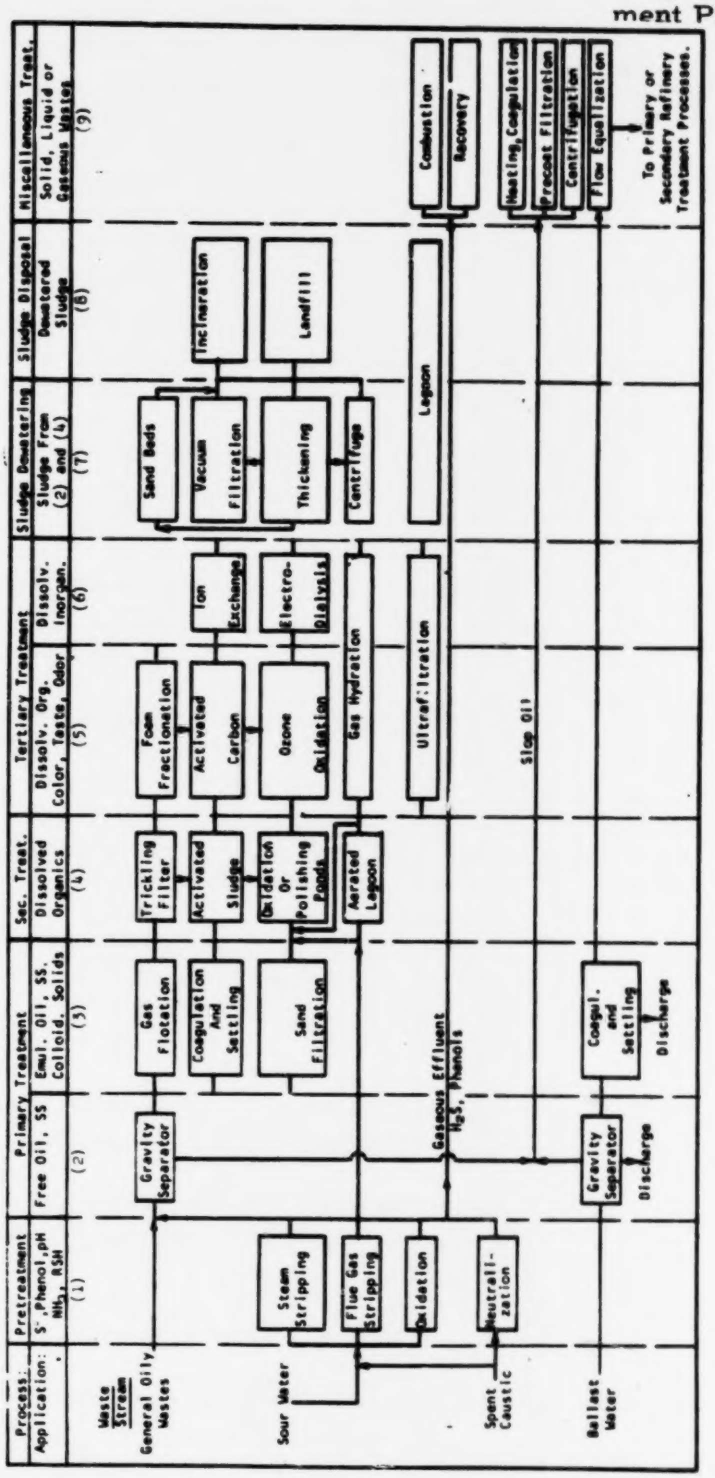

Process:
Application:
Pretreatment
S⁼, Phenol, pH NH₃, RSH
(1)
Primary Treatment
Free Oil, SS
(2)
Emul. Oil, SS, Colloid. Solids
(3)
Sec. Treat.
Dissolved Organics
(4)
Tertiary Treatment
Dissolv. Org. Color, Taste, Odor
(5)
Dissolv. Inorgan.
(6)
Sludge Dewatering
Sludge From (2) and (4)
(7)
Sludge Disposal
Dewatered Sludge
(8)
Miscellaneous Treat.
Solid, Liquid or Gaseous Wastes
(9)
Waste Stream
General Oily Wastes
Sour Water
Spent Caustic
Ballast Water
Steam Stripping
Flue Gas Stripping
Oxidation
Neutralization
Gravity Separator
Gas Flotation
Coagulation And Settling
Sand Filtration
Trickling Filter
Activated Sludge
Oxidation Or Polishing Ponds
Aerated Lagoon
Foam Fractionation
Activated Carbon
Ozone Oxidation
Gas Hydration
Ultrafiltration
Ion Exchange
Electro-Dialysis
Sand Beds
Vacuum Filtration
Thickening
Centrifuge
Lagoon
Incineration
Landfill
Combustion
Recovery
Heating, Coagulation
Precoat Filtration
Centrifugation
Flow Equalization
Gaseous Effluent H₂S, Phenols
Slop Oil
Gravity Separator
Discharge
Coagul. and Settling
Discharge
To Primary or Secondary Refinery Treatment Processes.

Table A-6-3
List of In-plant Control and Treatment Processes for Petroleum Refining Industry

Types of Wastes	Treatment Processes
Sour Water	Ammonia and Hydrogen Sulfide Recovery Process (by Chevron)(Expected removal: sulfide, 99.9%; ammonia, 99.9%) Stripping with Steam (Expected removal: COD, 40-93%; phenol, 0-30%; sulfide, 70-100%; ammonia, 40-95%) Stripping with Steam and Acid (Expected removal: phenol, 0%, sulfide, 85-100% ammonia, 0%) Stripping with Flue Gas (Expected removal: sulfide, 99%; ammonia 8%) Stripping with Flue Gas and Steam (Expected removal: phenol, 0-25%; sulfide, 88-100%; ammonia, 75-90%) Sulfide Oxidation Tower (with air and steam) (Expected removal: sulfide, 99-100%; ammonia, 80%)
Spent Caustic (Sulfidic)	Sulfide Oxidation Tower (with air and steam (Expected removal: sulfide, 100%) Neutralization + Steam Stripping (Expected removal: sulfide, 100%; alkalinity, 99-100%) Direct Sale to Paper Industry

Table A-6-3
(Continued)

Types of Wastes	Treatment Processes
Spent Caustics (Phenolic)	Neutralization with acid followed by separation (expected removal: oil, 99%; phenol, 90-95%, sulfide, 60-70%; alkalinity, 90-100%)
	Neutralization with flue gas (Expected removal: phenol, 90-95%; sulfide, 60-70%; alkalinity, 99-100%)
	Direct sale to chemical plant for recovery of acid oil (Cresylic Acid)
Spent Acid (from Alkylation Process or Lube Oil Stock Treating)	Treatment for acid recovery
	Neutralization with spent caustic or boiler blowdown
	Direct sale to acid manufacturer
Phenol-Bearing Wastes (process condensate or steam stripper condensate and bottoms)	Solvent extraction (PHENEX process) (expected removal: phenol, 75-90%
	Reuse at crude desalter (expected) removal: phenol, 60-90%)
	Reuse at cooling tower (expected) removal: COD, 70-90%; phenol, 99%)
Ballast Water (from "clean" ships)	Separate ballast tank
Ballast Water (from "Black" oil ship)	Separate ballast tank (with steam coil heating and chemical addition to break emulsions)

Table A-6-3
(Continued)

Types of Wastes	Treatment Processes
Copper and Lead-bearing Wastes (from Light Oils Treating Units)	Simple separator at source (spent caustic in the waste will precipitate copper and lead) (expected removal: Cu, greater than 95%; Pb, greater than 99%)
Fluoride-bearing Waste (from Hydrofluoric Alkylation Process)	Chemical precipitation with lime followed by sedimentation (expected removal: F, greater than 95%)
Chromium-bearing Waste (from Cooling Tower Blow-down when Chromate is used)	Reduction by reducing agent such as sodium sulfite, sodium bisulfite, sulfur dioxide (in flue gas), or ferrous sulfate (in pickle liquor) followed by precipitation with lime. (expected removal: Cr, greater than 95%) Ion exchange (expected removal: CR, greater than 95%)
Spent Aluminum Chloride (from Alkylation Process)	Incineration (special) Burial with crushed limestone Use as coagulating chemical for treatment of wastewater Combined with caustic soda to form aluminum hydroxide
Coke Fines (from hydraulic decoking of a delayed coker)	Air wetting of coke fines followed by sedimentation in a settling pit and water reuse (expected removal: suspended solids, greater than 95%)
Boiler Blowdown	Separate holding lagoon followed by neutralization with acid waste

Table A-6-3
(Continued)

Types of Wastes	Treatment Processes
Slop Oil	Separation in slop oil tank with steam coil heating and chemical coagulation
	Separation by vacuum filter
	Separation by centrifuge
Sanitary Sewage	Package sewage treatment plant
	Discharge to city sewer system
	Septic tank with effluent discharged to general oily sewer
	Septic tank followed by tile field
Contaminated Storm Drainage from Padded Process Areas or Tank Farms	Holding basin followed by controlled discharge to general oily sewer

APPENDIX A-6-24

TABLE A-6-4

Efficiency of Oil Refinery Waste Treatment Practices Based On Effluent Quality

	MPPI[5]	BOD	COD	Separable Oil	Emulsified Oil	Phenol	Sulfide S	Susp. Solids	Chloride	Ammonia	Acidity Alkalin.	Cyanide	pH	Toxicity	Temp.
PHYSICAL TREATMENT															
API Separators	R.W.	5-35[1]	5-30[1]	60-99	N.A.	Reduced	N.A.	10-50	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Earthen Separators	R.W.	5-50	5-40	50-99	N.A.	Reduced	N.A.	10-85	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	10-90[2]
Evaporation[3]	API Eff.	100	100	N.A.	100	100	100	100	100	100	100	100	N.A.	N.A.	N.A.
Air Flotation without chemicals	API Eff.	5-25	5-20	70-95	10-40	N.A.	Reduced	10-40	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CHEMICAL TREATMENT															
Air Flotation with chemicals	API Eff.	10-60	10-50	75-95	50-90	N.A.	Reduced	50-90	N.A.	Reduced	N.A.	N.A.	N.A.	N.A.	N.A.
Chemical Coag. and Precip.	API Eff.	10-70	10-50	60-95	50-90	N.A.	N.A.	50-90	N.A.	N.A.	Altered	N.A.	Altered	N.A.	N.A.
BIOLOGICAL TREATMENT															
Activated Sludge	API Eff.	70-95	30-70	N.A.	50-80	65-99	90-99	60-85	N.A.	50-95	Altered	65-99	Altered	Reduced	10-60
Aerated Lagoons	API Eff.	50-90	25-60	N.A.	50-80	65-99	90-99	0-40	N.A.	0-45	Altered	65-99	Altered	Reduced	10-90
Trickling Filters	API Eff.	50-90	25-60	N.A.	50-80	65-99	80-99	60-85	N.A.	50-95	Altered	65-99	Altered	Reduced	10-60
Oxidation Ponds	API Eff.	40-80	20-50	N.A.	40-70	65-99	70-90	20-70	N.A.	20-90	Altered	65-99	Altered	Reduced	10-90
TERTIARY TREATMENT															
Activated Carbon	SEC.[4] Eff.	50-90	50-90	N.A.	50-90	80-99	80-99	N.A.	N.A.	10-30	N.A.	80-99	N.A.	Reduced	N.A.
Ozonation	SEC. Eff.	50-90	50-90	N.A.		80-99	80-99	N.A.	N.A.	10-30	N.A.	80-99	N.A.	Reduced	N.A.

[1] BOD and COD from separable oil not included.

[2] Percent of difference between ambient temperature and waste temperature.

[3] Limited by meteorological conditions.

[4] Chemical or Biological Treatment.

[5] MPPI 'Most Probable Process Influent' indicates the kind and/or extent of prior treatment required for efficient utilization of the specific process under consideration.

the available waters. As water and air standards tighten, the release of effluents from production sites will be limited to a greater degree than now and may even be prohibited.

For these reasons, increased emphasis will be placed on reducing the volume of waste flows and on means to completely reduce the residues to an innocuous state. At present the "too hot to release" wastes may be disposed of in deep wells. However, this means of disposal may be curtailed much the same as ocean dumping. Should this occur, little choice remains but to render the wastes harmless or to place in acceptable land fill sites.

At present the petroleum industry is a leader in the treatment of waste waters. The 1967 Census of Manufacturing, Water Use in Manufacturing (Reference 6), provides the wastewater treatment data given in Table A-6-5.

The petroleum industry ranks high in the treatment of water prior to its release. For example, all industries discharge approximately 14.3 billion gallons annually (1967) and treat only 4.3 billion gallons. Such treatment does not, however, ensure that refinery and petrochemical wastes do not contain materials and suspensions which may be harmful to water quality.

Table A-6-5
Petroleum Refinery Disposal Processes

Treatment Method	Establishments	Treated Water Discharges (Billion Gallons)
Coagulation	19	19.5
Primary Settling	127	682.8
Secondary Settling	64	378.7
Trickling Filters	12	7.0
Activated Sludge	12	7.3
Digestion	10	2.5
Ponds or Lagoons	103	363.8
pH Adjustment	33	77.3
Sand Filtration	2	--
Chlorination	7	0.6
Flotation	57	420.3
Other	30	--

Total establishments surveyed	184
Total water intake	1426.9 billion gallons
Total treated water discharges	917.1
Total water discharges:	1217.0 billion gallons

The residual wastes remaining in such effluents were surveyed and documented by the American Petroleum Institute (Reference 7). Of a total of 260 operating refineries, 171 responded to the survey. These plants represent 93 percent of the U. S. capacity and included all of the petrochemical producers.

Estimated averages for all refineries and the reported characteristics are:

Effluent	Lbs/Day/1,000 bbl Crude
BOD	75
COD	250
Oil	30
Phenols	5
Suspended Solids	40
Dissolved Solids	1,200
Alkalinity	75
Sulphur	5
Phosphate	2
Ammonia Nitrogen	15

The overall net U.S. refinery effluent contaminant loadings following waste treatment were estimated as follows:

Parameter	Pounds Per Day
BOD	800,000
COD	2,500,000
Oil	360,000
Phenol	55,000
Suspended Solids	500,000
	4,215,000

The addition of these contaminats to the existing sludge piles, should water quality standards prohibit their continued release, will substantially increase the problems concerned with the disposition of sludge wastes.

Waste treatment processes for petrochemical plants are similar, in most respects, to those used by refineries. In fact, many modern refineries are also major producers of petrochemicals.

The actual compound in the waste effluents depends largely on the products produced in a particular plant and/or the treatment given the wastes prior to release. Organic pollution is difficult to define in terms of general factors or in terms of compounds within the waste streams. Products, by-products, and unconverted fuels are contained within the same waste streams and may produce, by interaction, additional products of unknown composition. Analytical techniques now available are insufficient to the task of continuously analyzing and establishing the composition of waste streams.

Although some organic compounds may be more readily removed in waste treatment, many are resistant to biodegradation, physical or chemical treatment. If any organic components can be detected in the wastes it must be assumed that toxic compounds have been released.

To attain a high degree of assurance that no organic compound which may have latent toxic, carcinogenic, mutagenic, or teratogenic is released, all organic material must be removed from the wastes.

Tables A-6-6 and A-6-7 show the waste treatment processes associated with various organic compounds (Reference 8).

An excerpt from The Characteristics and Pollutional Problems Associated With Petrochemical Wastes (Reference 9) is included after Tables A-6-6 and A-6-7. This excerpt provides a detailed appraisal of the current state-of-the-art of waste treatment in the petrochemical industry.

APPENDIX A-6-30

TABLE A-6-6

Waste Treating Process Being Used for Petrochemical Wastes

	Physical Treatment								Chemical Treatment			Biological Treatment			Ultimate Disposal						
Wastes from Petrochemical Operations	Sedimentation	Filtration	Flotation	Separators (API)	Stripping	Adsorption and Extraction	Evaporation	Submerged Combustion	pH Adjustment	Chemical Oxidation	Coagulation and Chemical Precipitation	Biological Filters	Activated Sludge	Lagoons	Controlled Dilution to Streams and Bays	At Sea	On Land Surfaces	Dumping or Burial	Deep Wells	Incineration	Salvage
Organic:																					
Acetaldehyde				1	2							3 4 5	6	7	1						
Acetic acid												4 8	3 6 9	7 10	X					11	
Acetone				1	4 12							4 8	3 6 13							11	
Acetylene derivatives				1											1						
Acrolein						X				X		X	X							X	
Alcohol, general						14						4					14			14	
Alcohols, high boiling												15	13		1				14		1
Allyl alcohol										X		15 16							X		
Allyl chloride																				X	
Aromatics, C_8				1																	X
Benzene				1								17		1	1					11	
Butadiene				1 18								X		X						X	
Carbonyl products															X				19		
Carbon tetrachloride																					X
Chlorinated hydrocarbons												5				20			14	19 21	22
Chloroform																				19	X
Cresols						23				23					X						X
Cuprous ammonium acetate											1				1						X
Cyanides					24	23				25 26		26			27		28			29	
Detergents				1					1												
Dichloropropane																				1	
Diethyl ether				1											X					X	
Diethyl formamide															X						
Distillate, aromatic				1																X	X
Divinylacetylene																					
Dodecyl																				X	
Dowtherm															X					X	
Ethyl alcohol					4 12							15 17	6		1				X		

Note: Processes being used are indicated by a reference number or an X.

TABLE A-6-6

WASTES FROM PETROCHEMICAL OPERATIONS	PHYSICAL TREATMENT								CHEMICAL TREATMENT			BIOLOGICAL TREATMENT			ULTIMATE DISPOSAL						
	SEDIMENTATION	FILTRATION	FLOTATION	SEPARATORS (API)	STRIPPING	ADSORPTION AND EXTRACTION	EVAPORATION	SUBMERGED COMBUSTION	pH ADJUSTMENT	CHEMICAL OXIDATION	COAGULATION AND CHEMICAL PRECIPITATION	BIOLOGICAL FILTERS	ACTIVATED SLUDGE	LAGOONS	CONTROLLED DILUTION TO STREAMS AND BAYS	AT SEA	ON LAND SURFACES	DUMPING OR BURIAL	DEEP WELLS	INCINERATION	SALVAGE
Organic:																					
Ethyl benzene				1																	
Ethyl chloride																				X	
Ethyl ether				1											1				X		
Ethylene diacetate																				X	
Ethylene dichloride																				X	
Ethylene oxide															X						
Ethylidene chloride																					
Epichlorohydrin												30								X	
Flux oil				1																X	1
Formaldehyde						21 31 32						30 33	3 21 32	3 7 30 33						11	
Formic acid												34	3							11	
Gasolines				1																	1
Glycerol													3		X			X	X	X	
Glycols													3 13							11	
Hydrazine																					
Hydrogen cyanide									X						X				X	18	
*Iso*butyl alcohol													13		1						
*Iso*butyl and *iso*propyl alcohol													6 13		1				X		
*Iso*propyl ether					X										X						
Kerosine				1																X	1
Ketones						14						14		1 14	X		14		14	14	
Mercaptans					36	X				36										X	X
Methanol												6 37	3 6 32	7						11	
Methyl acetylene															X						
Methyl chloride															X				38	X	X
Methyl formate																				X	
Methylene chloride																					
Monoethanolamine												15 17			1						1

NOTE: Processes being used are indicated by a reference number or an X.

TABLE A-6-6

Wastes from Petrochemical Operations	Physical Treatment								Chemical Treatment			Biological Treatment			Ultimate Disposal						
	Sedimentation	Filtration	Flotation	Separators (API)	Stripping	Adsorption and Extraction	Evaporation	Submerged Combustion	pH Adjustment	Chemical Oxidation	Coagulation and Chemical Precipitation	Biological Filters	Activated Sludge	Lagoons	Controlled Dilution to Streams and Bays	At Sea	On Land Surfaces	Dumping or Burial	Deep Wells	Incineration	Salvage
Organic:																					
Naphthas				1																	1
Naphthene						X														X	
Octyl alcohol															1						X
Octyl aldehyde															1						X
Picolines					1										1						
Phenolics					39 40	25 31 37 39 41 42			40	23		43 44	43 44	44	1				X	X	X
Polybutene				X											X					X	X
Polychloroethane																				X	
Polyethylenes, solid																				19	X
Poly*iso*butylene																				X	
Polymers				X																X	X
Propadiene																					
Propylene dichloride																				X	
Resins				33								33		33						X	X
Rubber				1		X														19	X
Soaps						X									X						
Sulfonates, petroleum			1						1						1						1
Tars	37			1																19 38 45	1
Terpenes												1 46		1							
Terpenes, sulfurized												1		1							
Toluene				1										1							47
Urea				1																X	1
Vinyl acetate															X						
Zylene				1																X	1
Inorganic:																					
Aluminum chloride															1			1		1	22
Ammonia					24				X			X	44	1	1						X
Ammonium nitrate												X	X	1	1						

NOTE: Processes being used are indicated by a reference number or an X.

TABLE A-6-6

Wastes from Petrochemical Operations	Physical Treatment								Chemical Treatment			Biological Treatment			Ultimate Disposal						
	Sedimentation	Filtration	Flotation	Separators (API)	Stripping	Adsorption and Extraction	Evaporation	Submerged Combustion	pH Adjustment	Chemical Oxidation	Coagulation and Chemical Precipitation	Biological Filters	Activated Sludge	Lagoons	Controlled Dilution to Streams and Bays	At Sea	On Land Surfaces	Dumping or Burial	Deep Wells	Incineration	Salvage
Inorganic:																					
Barium sludge														1	1						
Carbon bisulfide																				X	X
Carbon black		X																		X	X
Chlorine					X									X	X						
Chromates										25					X						
Chromic oxide catalyst										25											
Chromium oxide															X			X			X
Copper and compounds		X													1						
Copper chloride															X			X			X
Ferrous dichloride															X			X			
Hydrochloric acid									1 48						1				14		
Hydrogen sulfide					36				X	36										X	X
Lime		X							X						X		X	X			
Nitric acid									35 49						X						
Phosphoric acid catalyst									22						X		X	X			48
Potassium permanganate															X						
Sodium chloride															1				14 38 50		
Sodium hydroxide									X						X						
Soot	X	X	X																	29	
Sulfur dioxide						X			X						1						
Sulfuric acid									1 49 51						1				14	X	48
Sulfates															X				14		
Sodium sulfide	1								1						X			X			X
Waste caustic sodas										52					1 52				52	52	52

NOTE: Processes being used are indicated by a reference number or an X.

TABLE A-6-7

Summary of Treatment Methods for Petrochemical Wastes Classified by Plant Product

PLANT PRODUCT	PHYSICAL TREATMENT								CHEMICAL TREATMENT			BIOLOGICAL TREATMENT			ULTIMATE DISPOSAL						
	SEDIMENTATION	FILTRATION	FLOTATION	SEPARATORS (API)	STRIPPING	ADSORPTION AND EXTRACTION	EVAPORATION	SUBMERGED COMBUSTION	pH ADJUSTMENT	CHEMICAL OXIDATION	COAGULATION AND CHEMICAL PRECIPITATION	BIOLOGICAL FILTERS	ACTIVATED SLUDGE	LAGOONS	CONTROLLED DILUTION TO STREAMS AND BAYS	AT SEA	ON LAND SURFACES	DUMPING OR BURIAL	DEEP WELLS	INCINERATION	SALVAGE
General chemicals	53				39	39			53	29 53				53							
Nylon								50				50									
Nylon chemical intermediates	45	45			45		35 45			45		45		35 45	35 45		45		35 45	35 45	45
Organic chemicals				54			54		54											11	
Oxygenated hydrocarbons													3								
Photochemicals		55									55	1									
Powders												30									
Resins						25 31						33		33							
Rocket fuels				35					35			35									
Rubber, textiles, and plastics													3								
Synthetic rubber				18											18					18	

NOTE: Processes being used are indicated by a reference number.

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TREATMENT AND CONTROL OF PETROCHEMICAL WASTES

The treatment and control processes discussed herein are categorized as: (a) reduction of waste strength by in-process and inplant control measures, (b) physical treatment processes, (c) chemical treatment processes, (d) biological treatment processes, and (e) ultimate disposal techniques.

INTERNAL IMPROVEMENTS

The ideal method of controlling petrochemical pollutants is to eliminate them at the sources. This reduces the cost of waste treatment and in many cases provides valuable economic gains in the form of reduced losses of expensive petrochemicals and reduced intake of makeup water.

Reduction of Raw Material Losses - The losses of hydrocarbon raw materials from storage, transport, and processing facilities are an important source of water pollution in the petrochemical industry. Several improvements can be made by the industry to reduce the magnitude of these losses. The evaporation of light hydrocarbon from storage tanks can be controlled by floating roof tanks and the use of tank vents with vapor recovery lines. Purge lines used for process start-up and shut-down can be connected to vapor recovery systems The hydrocarbon losses from vacuum jets can be reduced by installing refrigerated condensors ahead of the jets or by connecting the jet exhaust to vapor recovery systems. Pipeline systems should be used to transfer raw materials whenever feasible in order to minimize transfer losses. Probably the most important source of hydrocarbon raw material loss is from malfunctioning equipment, leakages, etc. These losses can be corrected only by careful in-plant control.

Recovery of Usable Reaction Products - By-products represent a significant pollutional fraction of petrochemical wastewaters. In many cases, by-product recovery from the process wastes is justified, not only in terms of producing a product, but also in reducing the pollutional load to the waste treatment facility. The recovery of sulfur, for example, from petroleum hydrocarbons minimizes the sulfide and mercaptan pollution. The Claus process and a catalytic combustion process are currently used to convert hydrogen sulfide to elemental sulfur, thus, obtaining a reusable product.

Other sources of usable materials found in petrochemical wastes include catalyst complex metals and the tars from catalytic processes. Usually, the recovery of materials from the tars does not result in a direct profit to the petrochemical plant, but it may prove economically justified by reducing the pollutional discharge. Alkaline wastes from caustic washes are most significant. Some spent caustic solutions containing sulfides, phenolates, cresolates, and carbonates are marketable. Spent caustics which contain large amounts of phenols and cresole can be sold to processors who separate and purify the cresylic acid fractions for commercial use. Sodium sulfide can be separated from spent caustics high in sulfides, and marketed. Spent caustics can also be regenerated for reuse in washing processes by steam hydrolysis, electrolysis, air regeneration, and the use of slaked lime.

The recovery and recycling of process effluents containing unreacted raw materials is common to most petrochemical processes in which the process reaction is incomplete. Many of the secondary reaction by-products are also valuable either for use within the petrochemical plant or as marketable products. Some of the possible uses for by-products produced in three common petrochemical processes are shown in Table 8. The recovery and reuse of oils is very common in the petrochemical industry. Recoverable oils are reprocessed while those which are uneconomical to purify are used as fuels. Solvent recovery is practiced also, especially when the high costs of solvents are redeemable.

Process modifications can be classed as: (a) process selection, (b) prevention of product and chemical losses, and (c) modified operating conditions. If waste control is considered during process design, it often can be an important factor in the economics of operation. The substitution of continuous processes for batch processes tends to eliminate peak discharges of wastes, thus reducing the cost of treatment required for the waste. The use of downgraded chemicals in processes which do not require high-quality reactants facilities both process and waste control. This type of design often utilizes the waste effluents from one process as reactants in another.

Water reuse is often one of the most effective and economical means of decreasing the waste discharges from a petrochemical plant.

TABLE 8

USABLE SIDE PRODUCTS FROM SOME TYPICAL PETROCHEMICAL PROCESSES

(Reference 89)

Primary Product	Side-Products	Use
Butadiene:	Residue Gas (Hydrogen methane, ethane, carbon dioxide)	Fuel
	Propane and Propylene	Feedstock for Ethylene, Alkylation
	Butane and Butenes	Recycle for Butadiene Manufacture; Feedstock for Alkylation
	Aromatic Oils	Resin or Plastic Manufacture
Ethylene:	Residue Gas (Hydrogen, Methane)	Fuel
	Acetylene	Fuel for Welding Feedstock for Several Petrochemical Processes
	Ethane	Recycle for Ethylene Manufacture; Cracking Feedstock; Fuel
	Propane and Propylene	Propane Recycle for Ethylene Manufacture; Feedstocks for Several Petrochemical Processes (Alcohol, Alkylation, Polypropylene, etc.)
	Butane and Butylene	Feedstock for Synthetic Rubber Aviation Gas; Recycle to Cracking Process
	Aromatic Concentrate	Resin and Plastic Manufacture
	Heavy Oils and Tars	Refinery Charge Stock Fuel

TABLE 8 (Continued)

USABLE SIDE-PRODUCTS FROM SOME TYPICAL PETROCHEMICAL PROCESSES

Primary Product	Side-Products	Use
Ammonia:	Carbon Dioxide	Dry Ice, Bottled CO_2 Fuel Methanol Manufacture
	Helium	Lifting Gas Inert Gas
	Argon	Inert Gas

In addition to reducing water costs and waste treatment costs, water reuse increases the flexibility for plant expansion. Small quantities of concentrated wastes produced by reuse are easier to handle than larger quantities of dilute wastes, and the plant benefits by more freedom from upstream users.

Potential applications of water reuse include the utilization of poorer quality cooling and boiler water and also the reuse of contaminated steams in stripping operations. Water-use systems are classified as multiple recycle and cascade, but most frequently combinations of these schemes are employed.

Steam used for the stripping and quenching of process streams is an important source of waste. Condensates with high sulfide contents can be partially oxidized to sulfate and then used to generate low-quality stripping steam, although oxygen-demanding thiosulfates may be present. Another condensate reuse scheme has been described in which phenolic condensate from an olefin unit is washed with the fresh hydrocarbon feed-stream, thus removing the phenol from the condensate. Other volatile hydrocarbons are then steam-stripped from the condensate and reused to generate additional steam. A potential source of water for reuse in the petrochemical plant is for main boiler use. Boilers can often tolerate high dissolved solids concentrations, depending on the type of dissolved solids and the boiler design. Oils do not seem to deposit in boilers if chelating agents prevent other depositions from forming; thus, the oils are steam distilled or leave the boiler with the blowdown.

In-Plant Control - Operational control is one of the most important facets of pollution abatement. Inplant operational control includes: (a) maintenance of pipes, valves, fittings, pump seals, etc., to prevent leaks; (b) education of all plant personnel as to the effects of accidental and careless losses of materials; (c) changes in selected operational procedures; and (d) a highly developed monitoring system to detect the sources of occurrences of pollutants within the plant. A continuous monitoring program for important plant sewers can prove invaluable in locating malfunctioning process units and leaks.

Waste Stream Segregation - Three main segregated collection systems are normally used in petrochemical plants:

a) Area drains which carry off unpolluted cooling water and storm runoff from uncontaminated areas;

b) A contaminated water system which contains process waters, polluted cooling waters, and storm water runoff from contaminated areas; and

c) A sanitary sewerage system to collect plant domestic wastes.

Segregation of many process streams may be necessary due to the incompatibility of certain waste components. Wastes with high solids concentrations are usually segregated from oily streams since suspended solids tend to decrease the efficiency of oil separation units. Suspended solids also can interfere with oil recovery by increasing the solids contents of separator skimmings.

PHYSICAL TREATMENT PROCESSES

The types of physical treatment processes most commonly used in the treatment of petrochemical wastes include gravity separation, flotation, stripping processes, adsorption, extraction, and combustion. The waste from a petrochemical plant may require a combination of these processes if proper treatment is to be provided.

Gravity separation includes the removal of materials less dense than water such as oils and air-entrained particulates by flotation and the removal of suspended materials which are more dense than water by sedimentation. Sedimentation and flotation techniques commonly employ chemical conditioners to enhance the separation process. Many wastewaters from petrochemical operations contain significant quantities of free and emulsified oil which must be removed prior to subsequent treatment. Free oils are much easier to remove if their concentration is high. Slop oils which are recovered by the separation process can be cleaned and reused in various processing operations. Probably the most commonly employed separator design is that presented by the American Petroleum Institute. Reported efficiencies of some oil separators operated by the petroleum industry are given in Table 9. Although some reduction in chemical oxygen demand (COD) can be expected due to removal of oils and tars, little or no biological oxygen demand (BOD) removal will be prevalent.

Oil emulsions present the biggest problem of oil-water separation because they are not easily separated in gravity separators and other conventional separation devices. Emulsifying agents prevent the oils from coalescing and separating from the water phase. These emulsifying

TABLE 9

TYPICAL EFFICIENCIES OF OIL SEPARATION UNITS

Oil Content Influent (mg/1)	Oil Content Effluent (mg/1)	Oil Removed (%)	Type	Removed (%)	Removed (%)	Removed (%)	Ref
7,000-8,000	125	98-99+	Circular	-	-	-	115
3,200	10-50	98-99+	Impounding	0	-	-	83
400-200	10-40	90-95	Parallel Plate	-	-	-	59
220	49	78	API*	45	-	55	20
108	20	81.5	Circular	-	-	-	111
108	50	54	Circular	16	0	0	20
90-98	40-44	55	API	-	-	-	20
50-100	20-40	60	API	-	-	-	20
42	20	52	API	-	-	-	20

* API - American Petroleum Institute Standard Design

agents are surface-active agents and include catalysts, the sulfonic acids, naphthenic acids, and fatty acids, as well as their sodium and potassium salts. In an alkaline medium, calcium and magnesium salts form finely divided suspended solids which stabilize the emulsions. Sources of oil emulsions within a petrochemical plant include (a) crude oil desalting water, (b) condensates from distilling operations, (c) wash waters which follow caustic or acid chemical treating operations, (d) cooling waters from direct-contact condensors, (e) detergent manufacturing processes, and (f) equipment cleaning operations.

In order to separate the emulsified oils from the wastewater, the emulsion must be broken. The application of heat and pressure is probably one of the more effective methods used in de-emulsification of a waste. Distillation methods, in lieu of the heat requirements, are also effective in breaking emulsions as are filtration, acidification, and electrical methods.

Sedimentation processes are utilized in the pre- or primary treatment of petrochemical wastes with high suspended solids concentrations, in secondary clarification, and for a sludge thickening. Petrochemical wastewaters high in colloidal material must be chemically treated before adequate separation by sedimentation can be obtained. The removal of solids and oils from petrochemical wastewaters and the concentration of sludges can often be accomplished using the air flotation process. Air is dissolved under pressures of 30 to 60 psig with the wastewater to be treated. When the waste is then exposed to the atmosphere, minute air bubbles are released from solution and carry the suspended materials to the top of the tank. Gravity oil separators usually precede flotation units in most industrial applications. One of the big advantages of flotation over sedimentation is the shorter detention time required to clarify a waste by flotation, resulting in a unit of considerably smaller size.

Stripping processes are used to remove volatile materials from liquid streams. These methods are employed, generally, to remove relatively small quantities of volatile pollutants from large volumes of wastewater. Stripping is essentially a low-temperature distillation process whereby reduction of effective vapor pressure by the introduction of the stripping medium replaces the high temperature requirement. The two types of stripping agents commonly used are steam and inert gas.

The stripping of hydrogen sulfide and ammonia from sour water is probably the most common use of stripping employed by the petrochemical industry for waste treatment. The major stripping agents used to remove these contaminants are steam, natural gas, and flue gas.

Phenols also can be removed from aqueous waste streams by steam stripping which is applicable when a wastewater is subject to short variations in temperature, specific gravity, phenol concentrations, and suspended solids.

Volatile organic compounds can be stripped from aqueous wastes by using air as the stripping agent. The stripping rate of a volatile organic compound is a function of temperature, the stripping gas flow rate, and tank geometry. Laboratory testing has indicated that most of the BOD removal during the stripping of biodegradable volatile organic compounds was the result of biological action rather than physical stripping. If an organic compound is non-biodegradable and volatile, air stripping may be a feasible unit process.

Solvent extraction methods utilize the preferential solubility of materials in a selected solvent as a separation technique. The criteria for effective use of a solvent in wastewater treatment include (a) low water solubility, (b) density differential greater than 0.02 between solvent and wastewater, (c) high distribution coefficient for waste component being extracted, (d) low volatility and resistance to degradation by heat if distillation is used for regeneration or low solubility in liquid regenerants, and (e) economical to use. Equipment used for extraction of wastewater include counter current towers, mixer-settler units, centrifugal extractors, and miscellaneous equipment of special design.

Solvent extration has been found to effectively remove phenols. Tricresyl phosphates are excellent solvents for phenol due to their low solubility in water and their high distribution coefficients for phenol. However, they are expensive and deteriorate at high temperature. The electrostatic extractor employed in one phenol recovery process also recovers usable oil from wastewater which helps to make the process economical.

Other solvent extraction processes which have been used by the petrochemical industry include the extraction of thiazole-based chemicals from a rubber processing effluent with benzene and the extraction of salicylic and other hydroxy-aromatic acids from a wastewater using methyl-isobutyl-ketone as the solvent.

Adsorption is the process whereby substances are attached to the surface of a solid by electrical, physical, or chemical phenomenon. A carbon media has been the most successful adsorbent in removing certain refractory chemicals from wastewaters. Phenols, nitriles, and substituted organics are also adsorbed by carbon when present in low

The separation of surface-active agents from wastewater by induced foaming has been investigated in laboratory and pilot plant studies. Most of these studies have considered the removal of synthetic detergents from domestic wastes. It has been demonstrated that the surface-active agent, naphthylamine, which has little or no foaming ability, could be removed from solution by adding a foaming agent and inducing frothing.

CHEMICAL TREATMENT

The use of chemical systems for treating specific petrochemical wastes has been successfully employed. The most common methods for chemically treating petrochemical wastes include neutralization, precipitation, coagulation, and oxidation.

Neutralization and pH Adjustment - Neutralization of petrochemical wastes may be desired for several reasons, including:

a) Preparation of a waste for biological treatment,

b) Preparation of a waste for direct discharge,

c) Pretreatment for efficient coagulation,

d) Prevention of attack and corrosion of conveyance or process equipment, and

e) Prevention of unwanted precipitation of waste components.

Neutralization implies the adjustment of a wastewater pH to values at or near neutral pH; i. e., pH seven. Types of wastes generally neutralized are (a) dilute acid or alkaline wash waters; (b) spent caustics; (c) acid sludges from alkylation, sulfonation, sulfation, and acid treating processes; and (d) spent acid catalysts.

Sulfuric acid is the most common neutralizing agent used to neutralize spent caustic wastes. Acid sludges are normally hydrolyzed to free acids prior to their use as neutralizing agents. Spent caustic neutralization with an acid can be designed as a batch or a continuous system. The carbon dioxide in flue gases can also be used to neutralize spent caustic solutions. Flue gas neutralization is economically feasible provided that the gases are available at high enough pressure so that no compressor is required to inject them into the spent caustic solution.

concentrations. Additionally, benzene hexachloride and other chlorinated aromatics have been removed from pesticide manufacturing effluents by carbon adsorption. These chlorinated hydrocarbons can be recovered by regeneration with steam or with benzene.

Combustion processes are often feasible for disposal of petrochemical wastes which may be too concentrated, too toxic, or otherwise unsuitable for other methods of disposal. Combustion may be either direct or catalytic, depending on the waste to be oxidized. Incineration and submerged combustion are both direct combustion methods used by the petrochemical industry.

Submerged combustion has been used successfully in the total or partial evaporation of waste streams as well as concentrating dissolved solids. This method produces an effluent which either has reuse value or which is easier to dispose of than large volumes of the liquid waste. Incineration is the most commonly used combustion process for petrochemical wastes. Recently, fluidized bed incinerators have been used for burning oily sludges. The fluidized-bed incinerator is reported to provide better controlled combustion with lower requirements for excess oxygen than conventional incinerators for oily sludges. However, incineration occasionally converts a water pollution problem into an air pollution problem. For example, the air pollutants, sulfur dioxide, and hydrogen sulfide (from incomplete combustion) may be released to the atmosphere when petrochemical wastes are incinerated.

Filtration processes are used to remove and concentrate solids on oily materials from a waste stream. A filter can be specifically designed to remove small quantities of these materials as a final step in waste treatment, or it may be used to concentrate a waste so that further treatability of wastewater will be enhanced. Sludges produced by chemical coagulation and clarification of petrochemical wastes are often concentrated using centrifugation or vacuum filtration for easier handling and disposal. If effluent standards imposed on a plant are particularly stringent, a polishing filter employing sand filtration can be used to remove additional suspended material.

Miscellaneous Treatment Methods - Evaporation has been used as a method for treating some petrochemical wastewaters. Solar evaporation is feasible in areas with low annual rainfall and a relatively warm climate. Spraying the wastewater into the air will also increase the evaporation rate.

Spent acid catalyst and sludges have been spread in pits filled with lime, limestone, or oyster shells for neutralization. It should be noted that pH adjustment is commonly used to facilitate coagulation and precipitation.

Coagulation - Precipitation - The addition of coagulants under proper conditions causes the formation of a settleable precipitate containing waste materials which can be removed by conventional sedimentation or flotation processes. It should be noted that coagulation is always followed by some type of solids-separation process. The most commonly used coagulants are hydrated aluminum sulfate (alum), ferrous sulfate, and ferric salts. The conventional coagulation system utilizes a rapid mix tank followed by slow agitation of the mixture to promote growth of floc particles which settle. The sludge-blanket clarifier, which provides mixing, flocculation, and settling in the same unit, has had many industrial applications because of its compact dimensions.

Coagulant aids are sometimes necessary to promote bridging between floc particles and render the floc more settleable. The most common coagulant aids are activated silica, bentonite clays, the organic polyelectrolytes, and water treatment clarifier sludge. The three types of polyelectrolytes are categorized by their electrochemical nature, specifically, cationic, anionic, and nonionic.

A common application of coagulation in the petrochemical industry is the removal of emulsified oils from waste streams. Suspended solids and turbidity removals are often as high as 90 percent. However, most petrochemical wastes contain dissolved organic compounds which are not easily removed using coagulation methods. Coagulation has been used also to remove metals such as lead and zinc, water-soluble alkyl-aryl sulfonates by lime coagulation enhanced with ferrous sulfate, and low concentrations of sulfide which are precipitated with zinc chloride, ferric chloride, or copper sulfate.

Provisions must be made for the disposal of the sludges formed by the settled precipitates from coagulation-precipitation processes. Landfills are the most common form of inorganic sludge disposal, while organic sludges are usually dewatered by some filtration method and subsequently incinerated or buried.

Oxidation processes are used to treat both organic and inorganic contaminants using oxygen or other chemicals as the oxidizing agents. The oxidation of sulfides to sulfates using steam and air is an effective treatment method; however, wastes containing high concentrations of phenol cannot be treated in this manner because phenols interfere with sulfide oxidation. If large quantities of mercaptans or mercaptides are present in the waste, a reoxidizer may be required to ensure complete oxidation.

Catalytic oxidation is usually applied when the fuel value of a waste is too low for conventional incineration. The process was originally designed to operate in the vapor phase but has been successfully applied to aqueous wastes. Laboratory studies have shown that dilute aqueous organic wastes could be effectively oxidized at temperatures below 600°C, by using a copper-chromate catalyst. Investigations have demonstrated that hydrocarbons also could be oxidized by using metal oxide catalysts. The initial cost of catalytic oxidation units may be 20 to 30 percent greater than that for conventional incinerators, but for dilute organic wastes the operating costs may be 15 to 20 percent less.

Wastes containing sodium sulfite, which has a very high immediate oxygen demand, can be oxidized by bubbling air through the system. Iron catalysts have been employed occasionally to speed the oxidation reaction. The oxidation of sulfite to sulfate will increase the acidity of the waste and require subsequent neutralization. Diffused air has also been used to oxidize metal salts to insoluble hydroxides which were removed by sedimentation.

Chlorine has been used successfully to oxidize phenol and cyanide in petrochemical wastes. The oxidation of phenols must be carried to completion to prevent the release of chlorophenols which cause objectionable tastes and odors in drinking water. Cyanides can be oxidized to carbon dioxide and nitrogen by chlorination if the pH is maintained in excess of 8.5 and sufficient chlorine used, thus preventing the release of toxic cyanogen chloride. Chlorine dioxide has been shown to overcome these and other disadvantages of chlorine and hypochlorite oxidation, although this treatment is very expensive.

Ozone has been proposed as an oxidizing agent for phenols, cyanides, and other unsaturated organics because it is a considerably stronger oxidizing agent than chlorine. The chief disadvantage is the high initial cost of ozone generation equipment. Ozone has several advantages, one of which is its ability to react rapidly with phenols and cyanide.

Oxidation of phenols using hydrogen peroxide and ferrous salts has been investigated in the laboratory. Treatment of the industrial wastes in this case produced colored effluents which required additional treatment with alum.

Miscellaneous Methods - Ion exchange has been used to remove specific petrochemical pollutants. Quaternary ammonium anion resins have successfully removed phenols in the laboratory. However, regeneration of the resin was difficult and uneconomical. Salicylic acid recoveries of 80 percent were obtained from aspirin manufacturing effluents using a caustic-soda regenerated resin. Chemical reduction has been used in isolated cases to treat constituents of a waste stream.

BIOLOGICAL TREATMENT PROCESSES

Biological treatment of liquid petrochemical wastewaters is usually the most economical method of reducing its toxicity, organic content, and objectionable appearance. Extensive pretreatment is often required before a petrochemical waste stream can be treated biologically.

The applicability of biologically treating a particular waste is a function of the biological degradability of the dissolved organics present in the wastewater. When considering the economics of a biological treatment system, the time required to biologically degrade the dissolved organics is of primary importance. This degradation rate of an organic compound is a function of the molecular structure of the compound, the genera and species of microorganisms utilizing it as a food source, and the time required for the microorganism to develop the enzymes necessary for substrate utilization.

The biodegradability of an organic compound can be classified in several ways. The BOD parameter establishes a relative degree of biodegradability provided that acclimated seed is used for the test. There is much contradictory data relating the molecular structure of a compound to its biodegradability. However, the amenability or resistance of certain classifications of organic compounds to biological oxidation is well documented as described below.

a) Aliphatic or cyclic aliphatics are usually more susceptible to biological degradation than aromatics.

b) Unsaturated aliphatics, such as acrylics, vinyl, and carbonyl compounds are generally biodegradable.

c) Molecular size is significant concerning the biodegradability of an organic. Polymeric and complex molecular substances have shown resistance to biological degradation, part of which is attributed to the inability of the necessary enzymes to approach and attack susceptible bonds within the compound structure.

d) Structural isomerisms in organic compounds affect the relative biodegradability of many compound classes. For example, primary and secondary alcohols are extremely degradable while tertiary alcohols are resistant.

e) The addition or removal of a functional group affects the biological oxidation. A hydroxyl or amino substitution to a benzene ring renders the compound more degradable than the parent benzene, while a holgen substitution causes it to be less biodegradable.

f) Many organic compounds are extremely biodegradable at low concentrations but are bio-static or bio-toxic at higher concentrations.

The relative biodegradability of certain organic compounds is presented in Table 10.

Nutrients - Effective biological treatment of any organic contaminant requires the availability of essential nutrients for the organism. The mineral nutrients required by bacteria are available in sufficient amounts in most wastewaters, but nitrogen and phosphorus requirements are more critical and many petrochemical wastes are deficient in one or both of these elements. Nitrogen (N) and phosphorus (P) requirements for biological treatment have been related to the magnitude of the degradable organic content of wastewater as represented by BOD. Generally, a BOD:N:P ratio of 100:5:1 will provide sufficient amounts of these nutrients. Nitrogen is most readily available in its reduced form as ammonia, ammonium ion, or amino nitrogen. Organic nitrogen, nitrates, nitrites, and organic compounds containing these forms can also be used, but a considerable expenditure of energy is required to reduce these forms to ammonia nitrogen. Phosphorus is most readily available to the microorganisms as a phosphate.

Neutralization - Most biological treatment systems operate efficiently at pH values between five and nine, while optimum conditions usually fall within the pH six to eight range. Therefore, neutralization or pH adjustment is commonly required in many petrochemical wastewater treatment systems.

TABLE 10

RELATIVE BIODEGRADABILITY OF CERTAIN ORGANIC COMPOUNDS

(References 72, 73, 81)

Biodegradable Organic Compounds	Compounds Generally Resistant to Biological Degradation
Acrylic Acid	Ethers
Aliphatic Acids	Ethylene Chlorohydrin
Aliphatic Alcohols (normal, iso, secondary)	Isoprene
Aliphatic Aldehydes	Methyl Vinyl Ketone
Aliphatic Esters	Morpholine
Alkyl Benzene Sulfonates w/exception of propylene-based Benzaldehyde	Oil
Aromatic Amines	Polymeric Compounds
Dichlorophenola	Polypropylene Benzene Sulfonates
Ethanolamines	Selected Hydrocarbons Aliphatics Aromatics Alkyl-Aryl Groups
Glycols	Tertiary Aliphatic Alcohols
Ketones	Tertiary Benzene Sulfonates
Methacrylic Acid	Trichlorophenols
Methyl Methacrylate	
Monochlorophenols	
Nitriles	
Phenols	
Primary Aliphatic Amines	
Styrene	
Vinyl Acetate	

* Some compounds can be degraded biologically only after extended periods of seed acclimation.

Equalization - Petrochemical wastes are particularly subject to wide variations in flow and composition; thus, some form of equalization may be necessary to dampen these fluctuations and minimize transient effects which may adversely affect the biological process.

Pre- and primary treatment may be required to remove certain materials which would adversely affect the biological system. Oils are difficult for the organisms to metabolize due to their low solubility. Inorganic and non-biodegradable organic suspended solids will tend to build up in a treatment system, decreasing the proportion of active biological solids, and thus adversely affecting the treatment efficiency. Sulfides react with dissolved oxygen and reduce the available oxygen to the organisms. Heavy metals are toxic at defined concentrations and must be removed or reduced to safe levels. Also, waste streams with potentially toxic organic compounds should be separated and treated prior to discharge into the biological treatment system.

Temperature - The optimum temperature for most aerobic biological treatment systems is approximately 20 to 35°C. High temperatures of waste cause a decrease in oxygen solubility as well as increased oxygen utilization rates.

The activated sludge process is a continuous system where biological growths are mixed with wastewater, aerated, and then undergo biological sludge separation. A portion of the concentrated sludge is then recycled and mixed with additional waste. Completely mixed aeration designs are generally favored over plug flow systems for industrial waste treatment. These effluents discharged from completely mixed activated sludge systems generally are of better quality than those obtained from other biological processes in terms of organic and solids concentrations, but construction and operational costs are usually higher.

Parameters to be considered in the design of an activated sludge system include the fundamental factors of temperature, pH, and nutrient availability as well as the following:

a) The organic loading in terms of BOD applied per day per unit weight of biological solids,

b) The BOD removal kinetics of the specific petrochemical wastewater,

c) The quantity of biological sludge produced including accumulation of primary sludge,

d) The oxygen requirements of the system, and

e) The settleability of the biological sludge and the ease of gravity solids-liquid separation.

A summary of activated sludge plants treating petrochemical wastes, including information concerning the petrochemical products, applied loadings, nutrient requirements, and effluent quality are tabulated in Table 11. It should be recognized that many organic compounds can be chemically oxidized while remaining resistant to biological degradation, therefore being registered as COD but not BOD. The difference between the measured COD and BOD values indicates the magnitude of the organic fraction that is not readily amenable to biological degradation.

Trickling filters are commonly used in industrial waste treatment as "roughing devices" designed to equalize and reduce organic loads to activated sludge or aerated lagoon processes. Trickling filters employ microbial films which are attached to rock or synthetic media to remove organic materials from the wastewater solution. Most filter processes employ recirculation to increase the overall filter efficiency and to minimize shock loadings.

Although BOD removals obtained by trickling filters are usually less than those found in the activated sludge process, toxic effects are not as pronounced or perpetual. Additionally, filter design and operation is relatively simple. The recorded treatment of various chemical and petrochemical wastes using trickling filters is presented in Table 12.

Aerated lagoons are basins six to twelve feet in depth where oxygen is supplied mechanically. The two general types of aerated lagoons are the aerobic lagoon and the facultative lagoon. In the aerobic lagoon, all biological solids are kept in suspension, while sludge settling and consequent anaerobic decomposition are characteristic of the facultative aerated lagoon. In these lagoons, the solids concentration is allowed to reach an equilibrium concentration which depends on the organic concentration of the waste, the synthesis sludge rate coefficients, and the amount of power imparted to the basin liquid. Equilibrium-suspended solids normally range from 80 mg/1 to 250 mg/1.

High levels of treatment are generally not achieved in the aerated lagoons because of the BOD and COD associated with the effluent suspended solids and the relatively small number of active biological solids in contact with the wastewater. Aerated lagoons are particularly sensitive to transient organic loadings, toxic substances, and temperature

TABLE 11

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD			COD			Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
		In (mg/1)	Out (mg/1)	Rem (%)	In (mg/1)	Out (mg/1)	Rem (%)				
Refinery, Natural Gas Liquids, Chemical Specialties, Sanitary Sewage	4.87	90	20	78	200	90	55	0.1	None	Effl.phenol Effl. oil 0.5 mg/1	111
Phthalic Anhydride, Phenol, Salicylic Acid, Rubber Chem., Aspirin, Phenacetin	2.54	45.7	6.1	86.7				0.031	None	Brush Aeration, treats trickling filter effl. 55% sludge return	110
Refinery, Detergent Alkylate	2.45	345	50- 100	71- 85.5	855	150- 200	76.6- 82.5	0.08	PO_4	Phenols in = 160 mg/1 Sulfide in = 150 mg/1 Lab scale	44

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Butadiene Maleic Acid	2.0	2,000	25	98.8	2,990	480	84	0.24	NH_3		34
Butadiene Alkylate	1.5	1,960	24	98.8	2,980	477	98.3				34
Butadiene, Maleic Anhydride Fumaric Acid, Tetrahydrophthalic, Anhydride, Butylene Isomers, Alkylate	1.5	1,960	24	98.8	2,980	51	84	0.24 (MLVSS)	NH_3	Surface aerators wastes contain: alcohols, maleic acid, fumaric acid, cetic acid, C_1-C_4 aldehydes, furfural, water soluble addition products	84
Ethylene Propylene, Benzene	1.44	600	90	85	700	105	85		None	Oily waters: C_4-C_{10} oils 90% phenol removal	92

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5/\text{day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Naphthalene, Butadiene, Phenol, Acrylonitrile, Soft Detergent Bases, Resins, Other Aromatics	0.43	500	60	85-90	600	90	80-85	1.5	NH_3 PO_4	Sour waters: Oil in = 500 mg/1 Phen- in = 65 mg/1 pH adjustment, preceded by trickling filter, phenol removal = 99.9%	92
Phenol, 2, 4-D Aniline, Nitro-Benzene, Rubber Chem., Polyester Resins, Misc. Chem.	0.97	370	76	76.2				0.4	NH_3 PO_4	Accelator Pilot Plant Sewage added in ratio 1:600 once a wk	80

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Ethylene, Propylene, Butadiene, Benzene, Polyethylene, Fuel Oils	0.63	85	10	99	200	75	62.5			Quench waters, polyethylene and benzene wastes: preceding by trickling filter, effl. phenol 0.01 ppm	95
Refining Processes	0.51-0.63	125	15-25	80-88			65-80	0.28-0.4	PO_4	Phenol removal 85-94%; Oil removal 75-85%; Effl. phenol 0.5 mg/1; Effl. oil 1-2 mg/1; Temp. - 30° C	59

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Nylon	0.4	1,540	250	83.8							34
Petroleum	0.27	440	5	98.8	500	60	88			Phenol in = 25 ppm Phenol out = 1 ppm	34
Acrylic Fibers	0.252	2,260	118-226	90-95				0.4		Wastes contain acrylonitrile, dimethylamine, dimethylformamide, formic acid temp. 35-37°D return sludge 10-50% mechanical aeration	105

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Acetone, Phenol p-Cresol, Ditert.-Butyl-p-Cresol, Dicumyl Peroxide	0.216	3,560-4,400	1,030-750	71-83				0.89-1.1		Waste phenol 600 ppm Waste BOD 75,00-8,000 Waste diluted w/ effl. or water; pilot plant	33
Resins-Formalin, Aminoplasts, Phenol-Formald., Epoxy Resins, Textile Aux.	0.2	890	444-266	50-70				0.8-1.2		Diffused-air; domestic waste added; trickling filter follows 100% recycle sludge	98

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Ethylene and Propylene Oxides, Glycols, Morpholines, Ethylene-Diamines, Ethers, Piperazine	0.15	1,950	20	99	7,970-8,540	5,120-5,950	25-40	0.51	None	Lab Scale; extended aeration; high non-biodegradable fraction followed by stab. ponds	43
2, 4-D 2, 4, 5-T (Acid Wash Wastes)	0.1	1,670	125	92.5	2,500	500	80	0.78 (MLVSS)	NH_3 PO_4	1:1 mixture of acid wash streams diluted 9:1 prior to treatment to reduced chlorides, toxicity Lab Scale	42

TABLE 11 (Continued)

ACTIVATED SLUDGE TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	 Out (mg/1)	 Rem (%)	COD In (mg/1)	 Out (mg/1)	 Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5/\text{day}}{\text{lb MLSS}}\right)$	Nutrients Reqd.	Remarks	Ref
Cracking, Isomerization of Butane and Naphthene, Alkylation, Benzene, Toluene, Alcohols, Ketones, Cresylic Acids		1, 100	55-110	90-95				0. 5		90-95% phenol removed; Lab Scale	29
Ethylene, Acetylene			20					0. 23-0. 33	PO_4	Effl. phenol 0. 1 mg/1 Effl. oil 1 ppm	59
Nylon Manuf. - Adipic Acid Asidonitricz Alk. Organics				95			85	1. 0-3. 0	PO_4 NH_3	NH_4 OH used as nutrient and neutralizing agent waste diluted 2:1	30 86

TABLE 12

TRICKLING FILTER TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{1,000\ \text{ft}^3}\right)$	Deficient Nutrients	Remarks	Ref
Phenol, Salicylic Acid, Rubber Chem.	2.59	190	58	69.5				40.5	None	Rock Media, recirc. ratio 2.84:1	110
Aspirin, Phenacetin, Phthalic Anhydride	2.59	58	34	41.5				11.8	None	Rock Media, treats effl. from above filter, effl. to act. sl.	
Plastics, Amines, Enzymes	1.06	1,960	37	98.1	2,660	230	91.5			2 filters, followed	34
Ethylene, Propylene, Butadiene, Benzene, Polyethylene, Fuel Oil	0,63	170	85	50	400	200	50	89	None	Plastic filter media followed by act. sludge phenol removal = 95% influent diluted 2:1 w/ cooling water	95

TABLE 12 (Continued)

TRICKLING FILTER TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading lb BOD_5/day $\left(\frac{}{1,000\ ft^3}\right)$	Deficient Nutrients	Remarks	Ref
Aliphatic Acids, Esters, Alcohols, Aromatics, Amines, Inorganic Salts	0.57-0.86	1,100-2,300	23-470	57-99				42.1-82 (Both filters combined)	None	pH adjusted prior to treatment; 2 filters in series; Recycle on 1st state is 14-21:1	101
Ethylene, Propylene, Butadiene, Benzene, Naphthalene, Phenol, Acrylonitrile, Soft, Detergent Bases, Resins	0.43	1,300			1,500	450	60-70	140	NH_3 PO_4	Sour Waters, Rock Media	92

TABLE 12 (Continued)

TRICKLING FILTER TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{1,000\ \text{ft}^3}\right)$	Deficient Nutrients	Remarks	Ref
Pentaerythritoc Waste contains Formaldehyde, Sodium Formate, Methanol, Pentaerthritol	0.118	5,080- 5,800	225- 232*	95- 96*				1st stage 65	NH_3 PO_4 Yes	2 filters in series followed by act. sludge; recycle 40-1 on prim. filter, 13-1 second	32
Resins-Formaum, Aminoplasts, Phenol-Formal, Epoxy Resins, Textile Aus.	0.17			82.6				11.7	None	Both filters treat act. sludge effl. Blast furnace slag media Waste contains phenol, formaldehyde, methanol	98
	0.03			89.3				14.6	None		
Acrylic Fibers	0.32		13	30- 70		49	30- 70	50 84	NH_3 PO_4	Waste contains: acrylonitrile and zinc plastic filter media	91

* Entire Treatment System

TABLE 12 (Continued)

TRICKLING FILTER TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{1,000\ \text{ft}^3}\right)$	Deficient Nutrients	Remarks	Ref
Synthetic Resins-Phenol, Formaldehyde, Fatty Acids, Phthalic Acid, Maleic Acid, Glycerol, Pentaerythritol, H.C. Solvents				95-98				1st stage 85 (as Phenol) 2nd stage 11.6-18.2 gpd/ft^3		Plastic media, 2-stage treatment; Influent: Phenol = 4,500 mg/l Formaldehyde = 2,000 mg/l Fatty acids = 800 mg/l Phthalic and maleic acids = 1,000 mg/l Eff. phenol = 1.5 mg/1	27

TABLE 12 (Continued)

TRICKLING FILTER TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flor (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5/\text{day}}{1,000\ \text{ft}^3}\right)$	Deficient Nutrients	Remarks	Ref
Waste contains Acry-Acetone, Inhibitor oils, Alcohols, Esters, H_2SO_4 Organic Acids								51-79	None None	Original loading was lower value, loading increased w/o any adverse effects 15,000 lb BOD_5 removal per day	23

changes. A summary of reported data on treatment of petrochemical wastes by aerated lagoons is given in Table 13.

Waste stabilization ponds, which depend on the natural aquatic processes of bacterial and algal symbiosis, have been used successfully to treat petrochemical wastes. These ponds are often designed to polish the effluent from other biological waste treatment processes, but they have been used in some instances to treat entire plant wastes.

Waste stabilization ponds are categorized as being "aerobic," "facultative," or "anaerobic." The BOD removal found in these oxidation ponds is comparable to other biological unit processes, but the COD reduction capacity is often higher. However, highly colored substances reduce sunlight penetration and cause reduced photosynthesis, often affecting COD removal capacities. There also are toxic effects of many compounds on the pond algae which upset the symbiotic algal-bacterial relationship. Operational data on these ponds in the petrochemical industry are given in Table 14.

Miscellaneous Biological Treatment Processes - Cooling towers have been used as biological treatment devices and provide a method for reuse of water through the means of "free" biological treatment. Pilot plant investigations using a percolating and filter as a biological treatment process have indicated some promise.

Multiple Biological Treatment Schemes - The complexity of most biological treatment systems and the associated effluent quality requirements often circumvent single-stage biological treatment. Various combinations of biological processes, therefore, may be employed to achieve the desired effluent quality.

A general sequence of biological wastewater treatment process is demonstrated in Figure 13.

OTHER METHODS OF DISPOSAL

Dilution - This form of disposal is becoming less and less popular with regulatory authorities. However, certain petrochemical plants are allowed to discharge their wastes to receiving waters without treatment providing:

a) Sufficient receiving water is available as a diluent,

TABLE 13

AERATED LAGOON TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD			COD			Organic Loading $\left(\frac{\text{lb BOD}_5/\text{day}}{\text{Acre day}}\right)$	Nutrients Reqd.	Remarks	Ref
		In (mg/1)	Our (mg/1)	Rem (%)	In (mg/1)	Out (mg/1)	Rem (%)				
Refinery Butadiene, Butyl Rubber	19.1	225	100	55	610	350	43	4,630	PO_4	Followed by stab. pond temp = 32°C 30% COD is non-biodegradable Lab Scale	45
Refinery, Detergent Alkylate	2.45	345	50-100	71-85	855	150-200	77-83	6,300	PO_4	Influent phenols 160 mg/1 Influent sulfides 150 mg/1 Lab Scale	44
Cyclohexane, p-Xylene, Benzene, Paraffinic Naptha, o-Xylene Gasoline Nylon Fibers	0.51	100	25	75				400		Surface aeration, waste is extensively pretreated. Followed by pond	64

TABLE 13 (Continued)

AERATED LAGOON TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	COD In (mg/1)	COD Out (mg/1)	COD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5\text{/day}}{\text{Acre day}}\right)$	Nutrients Reqd.	Remarks	Ref
Chemicals for Lubricating Oils	0.2	465	180	61	1,050	600	43				34

TABLE 14

WASTE STABILIZATION POND TREATMENT OF PETROCHEMICAL WASTES

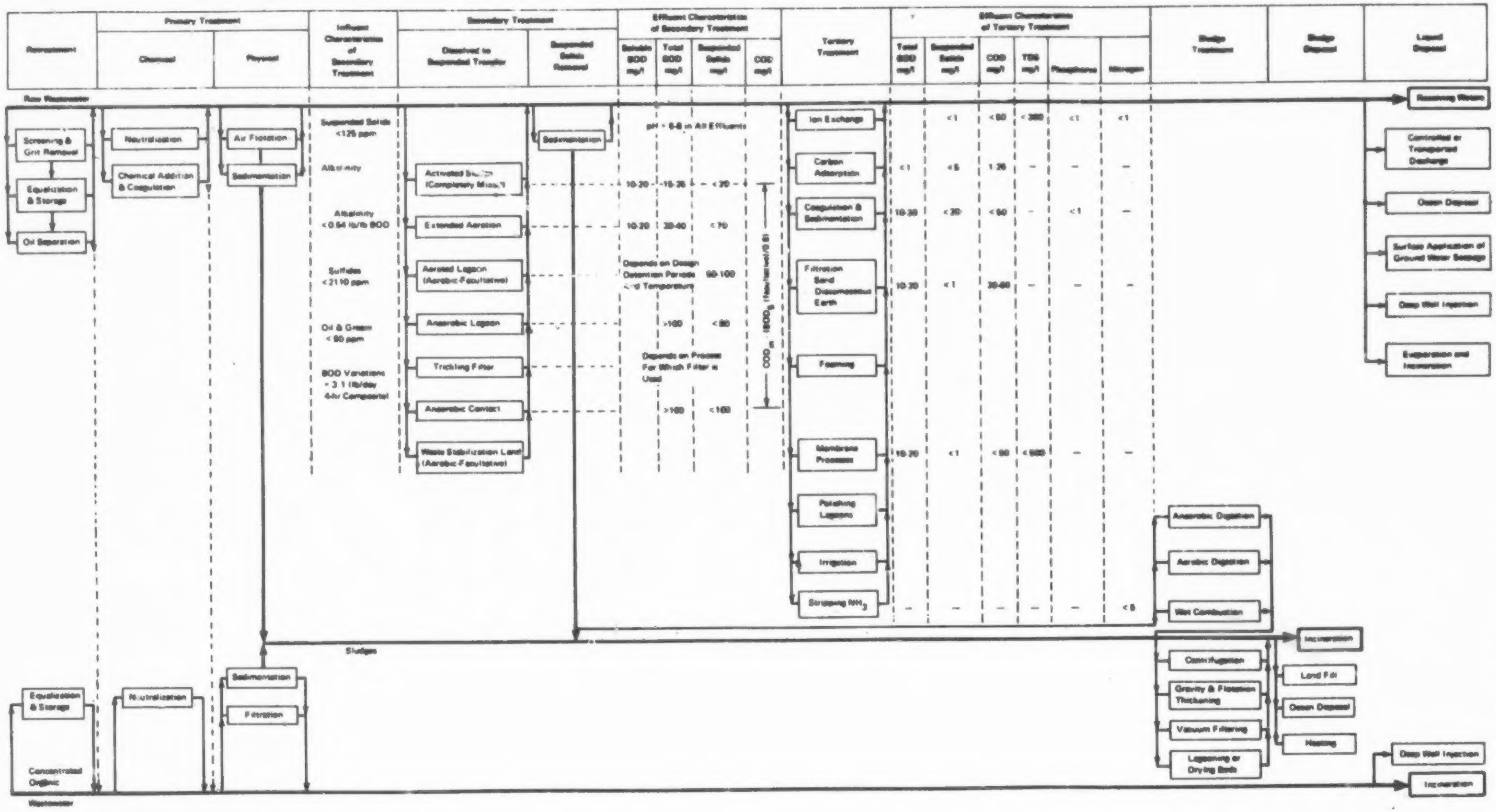
		BOD			COD						
Product and/or Process	Flow (MGD)	In (mg/1)	Out (mg/1)	Rem (%)	In (mg/1)	Out (mg/1)	Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5}{\text{Acre day}}\right)$	Nutrients Reqd.	Remarks	Ref
Refinery, Butadiene Butyl Rubber	19.1	100	50	50	350	200	43	Primary pond 91; Total ponds 46	None	Ponds in series after aerated lagoon Lab Scale	45
Resins, Alcohols,	5	500-1,000	400-700	20-60				96	None	Anaerobic	13
Amines, Esters,	5	400-700	25-50	88 96				164	None	Anaerobic	13
Styrene, Ethylene	5	25-50	5-30	40-90				5	None	Aerobic	13
Butane, Propane, Nat. Gas, Ethanol, Ethyl Chloride, Polyethylene, Ammonia, H_2SO_4	3.25	150	7-15	90-95	260			75	None	Facultative pond, 18 days detention Infl. SO_4 = 650 mg/1	113

TABLE 14 (Continued)

WASTE STABILIZATION POND TREATMENT OF PETROCHEMICAL WASTES

Product and/or Process	Flow (MGD)	BOD In (mg/1)	BOD Out (mg/1)	BOD Rem (%)	CCD In (mg/1)	CCD Out (mg/1)	CCD Rem (%)	Organic Loading $\left(\frac{\text{lb BOD}_5}{\text{Acre day}}\right)$	Nutrients Reqd.	Remarks	Ref
Refinery, Detergent Alkylate	2.45	50-100	20-50	50-80	150-200	120	20-40	95	None	After Aerated Lagoon Or Act. Sl Lab Scale	44
Plastics	1.69	686	186		1,681	590	65			Facultative Ponds	34
Ethylene and Propylene Oxides, Glycols, Morpholines, Ethylenediamines, Ethers, Piperazine	0.15	20			5,120-5,950	4,610-4,450	10-25	25	None	Lab Scale Facultative Ponds to remove some resid. COD. High nonbiodegradable fraction. After activated sludge	43
Mixed Petrochemicals				95-99			75-96	100		Faculatative ponds	113

FIGURE 13


Pretreatment
Primary Treatment
Chemical
Physical
Influent Characteristics of Secondary Treatment
Secondary Treatment
Dissolved to Suspended Transfer
Suspended Solids Removal
Effluent Characteristics of Secondary Treatment
Soluble BOD mg/l
Total BOD mg/l
Suspended Solids mg/l
COD mg/l
Tertiary Treatment
Effluent Characteristics of Tertiary Treatment
Total BOD mg/l
Suspended Solids mg/l
COD mg/l
TDS mg/l
Phosphorus
Nitrogen
Sludge Treatment
Sludge Disposal
Liquid Disposal
Raw Wastewater
Screening & Grit Removal
Equalization & Storage
Oil Separation
Neutralization
Chemical Addition & Coagulation
Air Flotation
Sedimentation
Suspended Solids <125 ppm
Alkalinity
Alkalinity <0.54 lb/lb BOD
Sulfides <2110 ppm
Oil & Grease <50 ppm
BOD Variations = 3:1 (lb/day 4-hr Composite)
Activated Sludge (Completely Mixed)
Extended Aeration
Aerated Lagoon (Aerobic-Facultative)
Anaerobic Lagoon
Trickling Filter
Anaerobic Contact
Waste Stabilization Land (Aerobic-Facultative)
Sedimentation
pH = 6-8 in All Effluents
10-20
15-25
<20
10-20
30-40
<70
Depends on Design Detention Periods and Temperature
50-100
>100
<80
Depends on Process For Which Filter is Used
>100
<100
Ion Exchange
Carbon Adsorption
Coagulation & Sedimentation
Filtration Sand Diatomaceous Earth
Foaming
Membrane Processes
Polishing Lagoons
Irrigation
Stripping NH3
<1
<50
<300
<1
<1
<1
<5
1-25
–
–
–
10-20
<20
<50
–
<1
–
10-20
<1
30-60
–
–
–
10-20
<1
<50
<500
–
–
–
–
–
–
–
<5
Receiving Waters
Controlled or Transported Discharge
Ocean Disposal
Surface Application of Ground Water Seepage
Deep Well Injection
Evaporation and Incineration
Anaerobic Digestion
Aerobic Digestion
Wet Combustion
Incineration
Centrifugation
Gravity & Flotation Thickening
Vacuum Filtering
Lagooning or Drying Beds
Land Fill
Ocean Disposal
Heating
Sludges
Equalization & Storage
Neutralization
Sedimentation
Filtration
Concentrated Organic Wastewater
Deep Well Injection
Incineration

b) There are no toxic or refractory compounds in the waste stream, and

c) The assimilative and recovery capacity of the receiving water is adequate.

Joint industrial-municipal treatment has been successful in certain cases, especially where small petrochemical plants are located near large metropolitan areas. Usually, some form of pretreatment is necessary before the industry discharges into the municipal sewer. It generally has been established, however, that individual treatment offers both economic and political advantages, particularly where large volumes of petrochemical wastewaters are involved.

Disposal wells used for the subsurface injection of wastewater are listed in Table 15. Most of the petrochemical wastes noted in Table 15 must be pretreated prior to injection. The more common formations suitable for injection of wastes include unconsolidated sands, limestones, and dolomites. The dangers of contaminating potable water-bearing formations can be assessed by studying the overlying and underlying strata and locating unplugged wells in the contiguous area.

Ocean Outfall - The direct discharge into the ocean is feasible when locations permit. Most liquids flow through outfall pipelines, the distance of discharge from shore depending on the nature of the wastewater, the ocean currents, and shoreline use. Barge disposal is another method of conveying wastes to the ocean for disposal.

Submerged combustion is the burning of a gaseous fuel in a specially designed burner with the burner chamber submerged in the wastewater. This device has been used successfully in totally or partially evaporating waste streams, concentrating any dissolved solids, either which have reuse value or which are easier to dispose of than large volumes of the liquid waste.

A submerged combustion unit reduced 75 percent of the volume of a nylon waste stream, the remainder of which was mixed with other process streams and treated biologically. A polymeric waste stream containing suspended synthetic rubber particles, organic solvents, inorganic salts, and synthetic detergents was not amenable to biological treatment and, consequently, treated by submerged combustion. This waste stream was evaporated to about 10 percent of its original waste volume with the resulting slurry emptied to a drying bed.

TABLE 15

PETROCHEMICAL WASTE DISPOSAL BY DEEP WELL INJECTION - TYPICAL INSTALLATIONS

Type Waste	Flow (gpm)	Depth (ft)	Injection Pressure (psia)	Formation	Required Pretreatment	Ref
Acrylonitrile and Detergent Manuf. Wastes: COD = 17, 500 mg/1; pH = 5. 4, SO_4 = 10, 000 mg/1	650	7, 203	Up to 2, 000	Sat. Brine, Miocene Sands	Neutralization; Settling and Equalization in Pond; Coagulation pH Adjustment and Clarification; Gravity Sand Filters	92
10- 15% NaC1; Diss. Metal Salts; Trace Organics; pH 7. 5- 8. 5	500-600	4 wells:	200	Unconsolidated Brine Sands	Oil Separation; Settling; Pressure Leaf Filtration; Diatomite Filtration	54 31
Refinery and Petrochem. Cooling Water Blow-down Boiler Blow-down, Process Waters	500	1, 200	75	Sandstone		48
Petrochem. Waste Organic Nitrogen Nitrites COD = 20, 000 ppm pH = 12 Uranium 238	400	6, 700	400	Sands	Neutralization, Precipitation - Sedimentation, Filtration	48

TABLE 15 (Continued)

PETROCHEMICAL WASTE DISPOSAL BY DEEP WELL INJECTION - TYPICAL INSTALLATIONS

Type Waste	Flow (gpm)	Depth (ft)	Injection Pressure (psia)	Formation	Required Pretreatment	Ref
Phenolic Waste: COD= 12,000 ppm; 850 ppm Phenol; 150 ppm Oil; pH 10.8	300	6,330	1,000	Sat. Brine, Miocene Sands	Neutralization with H_2SO_4; Clarifier, Pressure Sand Filter	92
Aromatics Phenols 1,000-2,000 ppm COD 10,000 ppm pH 10.7	300	6,100	1,000	Miocene Sands		48
0.3% Acetic Acid Chlorinated Derivatives	204	3,700	2,000	Miocene Brine Sand	Cool to 150°F. Adjust pH to 4.0-5.0, Settling Coal Filter; Cartridge Filter for Solids 10	115
Terephthalic Acid Manuf. Cooling and Boiler Blow-down, Process Wastes Containing Organic Acids, H. C., inorganics	150	5,600		Sands	Settling, Filtration	48

TABLE 15 (Continued)

PETROCHEMICAL WASTE DISPOSAL BY DEEP WELL INJECTION - TYPICAL INSTALLATIONS

Type Waste	Flow (gpm)	Depth (ft)	Injection Pressure (psia)	Formation	Required Pretreatment	Ref
Nylon, Ammonia, Olefins, Polyolefins Refinery, Butadiene, Sytrene, Synthetic Rubber 1	Small-96	5,802	800-1,100	Limestone	Conventional Waste Treatment, 0.3% by Volume of Acid, Added Before Injection	71
Cuprous Ammonium Acetate from Butadiene Pond; Caustic Waste from Ethylene Prod. Caustic and Phenols from Refinery	85	4,000	1,500-2,000		Equalization, Settling	95
Refinery Cooling & Boiler Blowdown, Process Wastes, Brines	50	5,000	600	Sandstone	Settling and Storage	48
Ammonia Prod.	45	1,000	225	Sandstone	API Separator	48
Hydrochloric Acid	40	1,200	14.7	Sandstone	None	48

TABLE 15 (Continued)

PETROCHEMICAL WASTE DISPOSAL BY DEEP WELL INJECTION - TYPICAL INSTALLATIONS

Type Waste	Flow (gpm)	Depth (ft)	Injection Pressure (psia)	Formation	Required Pretreatment	Ref
Detergent Product 32% HC1 Benzene Chlorinated HC	35	3,400		Miocene Sands	Dilution with Equal Volume Fresh Water	48
Spent Alkylation Acid- 90% H_2SO_4; 7% Oil; 3% H_2O	1	5,100				55
Filtrates and Distillates from Chloromycetin Manuf: BOD_{20} = 45,000 ppm; pH 3.5, Diss. Solids = 50,000 ppm		1,400		Saturated Brine, Sand		2
Saturated NaCl, Conc. Ca-Mg, Liquors, Phenols Chloro-Phenols, Bis-Phenols, Methocel, Weak Caustic Washes		3,000		Limestone	Suspended Solids Removed	

Volatile organic compounds in the polymeric waste, such as alcohols and amines, were oxidized or burned so that no odors were detected in the surrounding area.

Incineration of combustible and partially combustible liquid wastes is often a feasible method of disposing of concentrated process streams. The properly designed incineration system considers time, temperature, and turbulence. Sufficient residence time should be provided to permit complete oxidation of the organic material, the temperature should be high enough for the reaction to proceed, and the system should be sufficiently turbulent to ensure that the oxygen in the air is contacted with the dissolved organic material.

Although incineration is a practical means of handling a wide variety of effluents, it should be evaluated only in the light of the total pollution problem, particularly air pollution.

4. HAZARD EFFECTS OF WASTES

Effluent from treatment processes may contain substances that will cause immediate effects on the environment or may initiate or perpetuate a chain of events that will ultimately damage the environment or its inhabitants. The general categories of effluents from refineries and petrochemical production can be grouped under air, water, or solid waste contaminants.

Air effluents include all materials that escape to the air from failure to maintain control (spills, leaks, evaporation, etc.) or from processes that release contaminants into the air. Air pollution abatement equipment will reduce, but may not entirely eliminate, the release of industrial pollutants.

As tighter control is obtained over air pollutants, the materials formerly released into the air may be captured as liquid or solid wastes. These wastes may contain compounds that are individually harmful and may also be capable of degrading the aquatic or land environment because of the impact of innocuous solid materials.

Some of the debilitating effects that suspended solids may have on aquatic life include:

- Entrapment of small aquatic plants, eggs and animals
- Destruction of bottom organisms

- Destruction of shell and fish spawning beds
- Depletion of oxygen
- Change in pH
- Gill damage to fish
- Reduce or destroy plant photosynthesis.

Solids may also interfere with the irrigation of soils by forming an impervious blanket that reduces the penetration of air and water, by fouling recreational areas, by filling river channels or causing shoals, and by damaging process equipments such as pumps, heat exchangers, and process lines.

Complete elimination of solids from release into the air by appropriate treatment will increase the solid wastes to be disposed of. Increased solid waste may create landfill erosion and water table pollution problems unless carefully designed and operated.

These effects are in addition to those that may result from the toxic properties of air, water or solid waste releases. The amounts of solid materials released into the water environment is both a measure of the environment damage that may occur solely from the effect of solids and a measure of the solid waste disposal problem if all such solids are removed from the water.

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APPENDIX A-7

SIC 31—LEATHER AND LEATHER PRODUCTS

SIC 311— LEATHER TANNING AND FINISHING

1. INDUSTRY DESCRIPTION

This industry includes establishments engaged in tanning, currying, and finishing hides and skins into leather. The leather tanning and finishing industry is characterized by three types of tanneries: regular tanneries, leather converters, and contract tanneries. The regular tanneries buy raw materials; tan, curry, and finish the hides and skins; and sell the finished products. The converters buy the raw materials, contract with tanneries to convert to finished goods, and then sell the products. The contract tanneries perform only the processing function; they do not buy raw materials (hides and skins), nor do they sell the finished product.

The industry is concentrated in New England and the Mid-Atlantic States as shown in the accompanying tabulation.

	Establishments (1968)	
Division	Total	20 or More Employees
New England	183	93
Middle Atlantic	176	68
East North Central	74	51
West North Central	13	7
South Atlantic	26	18
East South Central	12	10
West South Central	9	2
West	26	29
	519	258

The following table indicates the wide variation in establishment size (1968 data).

Establishments	Size of Establishment (No. of Employees)	Total Number of Employees
146	1-4	300
52	5-9	300
63	10-19	900
98	20-49	3,100
73	50-99	5,300
57	100-299	9,100
25	250-499	8,000
4	500-999	3,700
1	1000-2499	

Although New England and the Middle Atlantic States have 359 of the 518 tanneries (nearly 70 percent), they do less than half of the total business (approximately 427 million in a total of 870 million). Fewer but larger tanneries characterize the other areas of the country.

Employment has remained relatively static over the past ten years (1958-68) declining slowly from 37,000 in 1958 to 30,700 in 1968. The value added has varied from year to year within the range of $740 to $940 million.

Based on an approximation of gallons of water used for each pound of hide processed and an estimate that approximately 1,700 million pounds of hides were processed ($847 million value @ 50¢

per pound), the total effluent in 1968 is estimated at 15,600 million gallons. The estimate made by the Bureau of the Census, based on a special water use study, was 15 billion gallons. Of this amount, it is estimated that 10 billion gallons were treated prior to discharge. Sludge is approximately 3.5 percent of the effluent, or 500 million gallons of sludge must be dumped annually. The content of such sludge is approximately 95 percent water and 5 percent solids. The solids are 55 to 60 percent organic material, the balance being inorganic salts.

Assuming that 10 gallons of the effluent streams' biological oxygen demand (BOD) content is equivalent to the wastes of one person (Reference 1), the 15 billion gallons discharged annually is equivalent to the wastes of approximately 4 million people.

2. INDUSTRY GROWTH PATTERNS AND PRODUCTION TRENDS

Growth trends in the tanning industry are toward fewer and larger plants and the application of new technology. The number of tanneries has decreased constantly over the past 100 years, from a total of about 7,500 in 1867, to about 250 as of 1965, as illustrated below:

Year	No. of Tanneries
1867	7,500
1900	1,000
1952	443
1965	250

In general the industry can be characterized as "old", in terms of plant age. However, due to modernization programs, most plants employ relatively new technology.

Overall production trends have remained relatively static over the past 15 years, with cattle hides delivered fluctuating between about 30 to 35 million per year.

About 89 percent of all leather is used for making shoes. While the U. S. leather industry has shown no growth during the past 15 years, the U. S. population has about doubled. Imports of footwear leather have increased about 500 percent in dollar value, and U. S. exports have decreased by about 50 percent, as shown below:

Year	Leather Footwear		All Leather	
	Imports ($)	Exports ($)	Imports ($)	Exports ($)
1951	24,647,000	19,063,000	---	---
1963	80,687,000	8,628,000	143,000,000	17,084,000
1966	128,255,000	8,856,000	243,365,000	24,539,000

3. STANDARD PRODUCTION PROCESSES AND WASTE MATERIALS

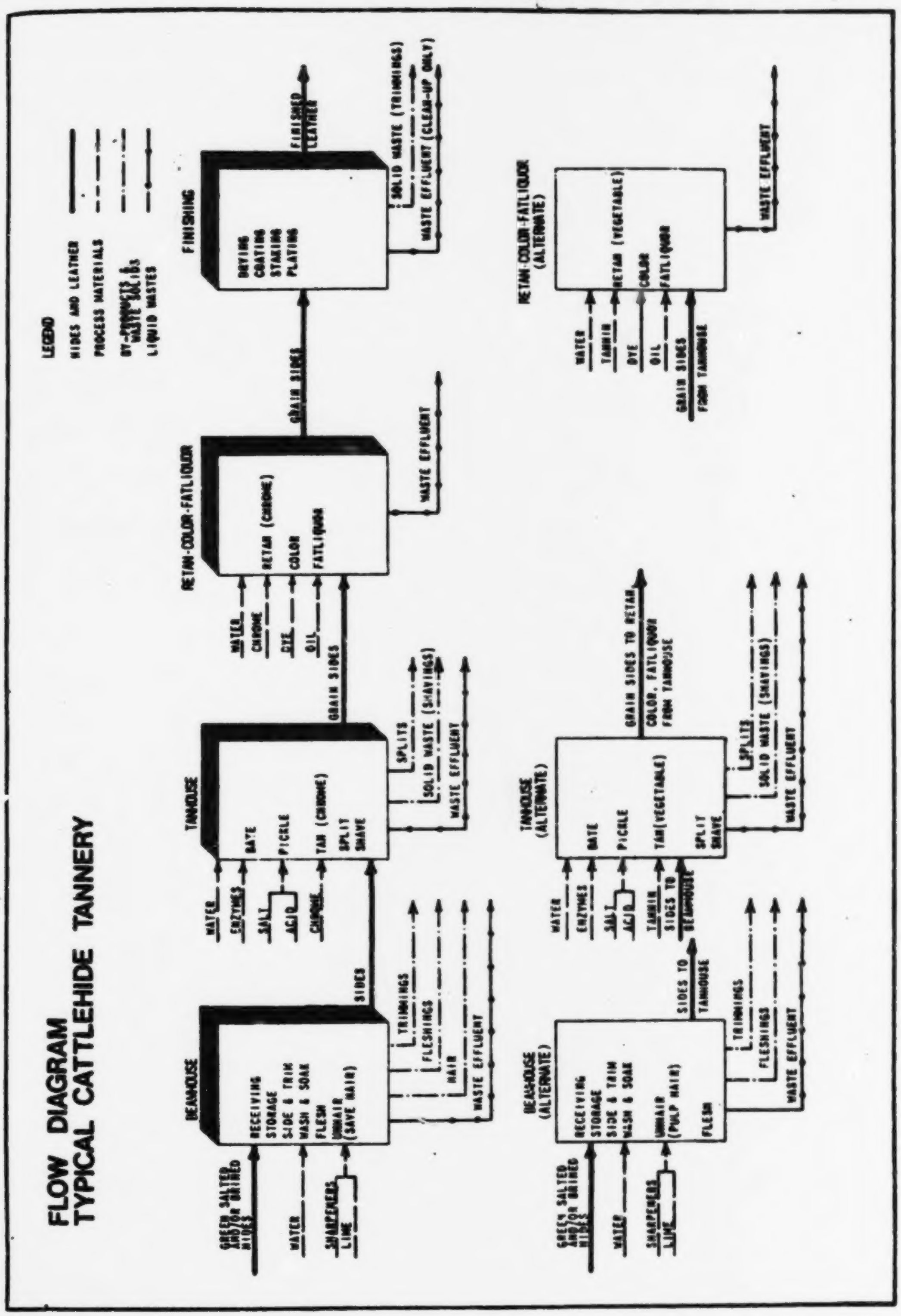
Tanning is the process of converting animal skin into leather. Generally, it consists of the reaction of collagen fibers with tannin, chromium, alum, or other tanning agents, to remove the undesirable protein in the skin. Due to individual preferences as a result of past experience in leather production, there is a significant variance in processing techniques of tanners.

(1) Typical Processes in the Tanning Industry

The following paragraphs present a general description of the manufacturing processes. In order to simplify the descriptions and characterizations of waste loads, the following standard processes are treated individually: beamhouse and tanhouse; retan, color, and fat liquor; and finishing. A typical flow diagram of cattlehide tanning is illustrated in Figure A-7-1. This identifies the flow of raw materials, process materials, and waste materials.

Although the processes for cattlehides, pigskins, and sheepskins differ somewhat, they are combined into a single general description for the purposes of this report. The major difference is that in the typical pigskin and sheepskin operation, the beamhouse processes are largely eliminated, since they are performed prior to arrival of the skins at the tanning. The trend in cattlehide processing is also in this direction, with major beamhouse operations increasingly being performed at the source of supply.

FIGURE A-7-1
Environmental Protection Agency
Flow Diagram —
Typical Cattlehide Tannery


FLOW DIAGRAM
TYPICAL CATTLEHIDE TANNERY
LEGEND
HIDES AND LEATHER
PROCESS MATERIALS
BY-PRODUCTS & WASTE SOLIDS
LIQUID WASTES
BEAMHOUSE
GREEN SALTED AND/OR BRINED HIDES
WATER
SHARPENERS
LIME
RECEIVING
STORAGE
SIDE & TRIM
WASH & SOAK
FLESH
UNHAIR (SAVE HAIR)
SIDES
TRIMMINGS
FLESHINGS
HAIR
WASTE EFFLUENT
TANHOUSE
WATER
ENZYMES
SALT
ACID
CHROME
BATE
PICKLE
TAN (CHROME)
SPLIT
SHAVE
SPLITS
SOLID WASTE (SHAVINGS)
WASTE EFFLUENT
GRAIN SIDES
RETAN-COLOR-FATLIQUOR
WATER
CHROME
DYE
OIL
RETAN (CHROME)
COLOR
FATLIQUOR
WASTE EFFLUENT
GRAIN SIDES
FINISHING
DRYING
COATING
STAKING
PLATING
FINISHED LEATHER
SOLID WASTE (TRIMMINGS)
WASTE EFFLUENT (CLEAN-UP ONLY)
BEAMHOUSE (ALTERNATE)
GREEN SALTED AND/OR BRINED HIDES
WATER
SHARPENERS
LIME
RECEIVING
STORAGE
SIDE & TRIM
WASH & SOAK
UNHAIR (PULP HAIR)
FLESH
SIDES TO TANHOUSE
TRIMMINGS
FLESHINGS
WASTE EFFLUENT
TANHOUSE (ALTERNATE)
WATER
ENZYMES
SALT
ACID
TANNIN
SIDES TO BEAMHOUSE
BATE
PICKLE
TAN (VEGETABLE)
SPLIT
SHAVE
GRAIN SIDES TO RETAN
COLOR, FATLIQUOR FROM TANHOUSE
SPLITS
SOLID WASTE (SHAVINGS)
WASTE EFFLUENT
RETAN-COLOR-FATLIQUOR (ALTERNATE)
WATER
TANNIN
DYE
OIL
GRAIN SIDES FROM TANHOUSE
RETAN (VEGETABLE)
COLOR
FATLIQUOR
WASTE EFFLUENT

1. Beamhouse Operation Include Unhairing and Preparation of Hides for Tanning

The beamhouse operation is the initial step in the tanning process. Generally it involves washing, to get rid of excess materials and storage brine, and then various processes to remove excess hide, flesh, and hair. Beamhouse processes are as follows:

- Receiving and storage is the initial beamhouse operation. Typically, this includes the delivery of cured green salted or brined hides in bundles of about 3,200 cubic feet measuring about 20 by 40 by 4 feet. These bundles are stored as delivered until processing begins.
- Siding and trimming involves unpacking the hides, trimming off excess material, about 2 to 3 percent of the hide, and siding or cutting the hide in half along the backbone.
- Washing and soaking takes place in vats or drums where excess dirt, salt, blood, manure, and nonfibrous proteins are removed.
- Green fleshing involves the removal of attached adipose fatty tissue and meat by processing hides through a fleshing machine.
- Unhairing is the removal of hair by chemical loosening, followed by machine pulling or chemical dissolving. Pulling is done if hair is to be recovered as a by-product. Dissolving, also referred to as "pulping" or "burning", is accomplished in a lime slurry with sodium sulfide or sodium sulfhydrate and does not yield a recoverable by-product.
- Lime splitting involves the slitting of a hide into two layers. The "split" or the upper flesh side is sold or discarded while the "grain" is processed for leather. Normally, splitting is done only with pigskin hides.

Beamhouse processes are the greatest single source of tannery wastes. The unhairing process in particular produces about 50 percent of the tannery total BOD and about 30 percent of the waste volume. The stock waste water is high in solids and is 10 to 15 percent of the total tannery wastewater discharge and 15 to 20 percent of the BOD. Waste materials from the beamhouse include:

- Hide trimmings
- Dirt, salt, blood, manure, and nonfibrous proteins
- Fats
- Alkalines
- Sulfides
- Proteins (dissolved)
- High BOD
- Lime
- Sodium sulfide

2. Tanhouse Processes Convert Hide Fibers into Leather

The tanhouse operations include the basic chemical processes necessary to convert hide fibers into leather. These operations include the following:

- Bating involves the placing of the hide in a solution of ammonium salts and enzymes. This de-limes the hides, reduces swelling, peptizes fibers, and removes protein degradation products.
- Pickling prevents precipitation of chromium salts in the tanning process and is done by immersing the hides in a brine and acid solution.

- Tanning involves both vegetable tanning and chrome tanning. Vegetable tanning is used for heavy leather such as sole leather, mechanical leather, and saddle leather. Hides are immersed in vats containing a solution of plant extracts such as vegetable tannins. Chrome tanning, used for the majority of light leathers, consists of immersing hides in drum baths containing proprietary mixtures of basic chromium sulfate.

Tanning liquor wastes are second to beamhouse wastes in concentration of effluents. Spent vegetable tannins are highly colored and account for 5 to 10 percent of the total waste flow and 25 to 30 percent of the total BOD from the tanning process. Batepool wastewater is usually about 40 percent of total tannery wastewater flow and 15 percent of the BOD. These wastes include:

- High concentrations of dissolved organic solids (vegetable tanning)
- High concentrations of dissolved inorganic solids and chromium (chrome tanning)
- High coloration
- High odors
- Total plant BOD (5 percent)
- Total plant waste volume (5 percent)
- Brine and acid from pickling.

3. Retan, Color, Fat Liquor Processes

As the names imply, these processes involve coloring and oiling the hides to produce the desired leather product. These processes are as follows:

- Retanning is used for hides that have not been fully tanned in the initial tanning processes.

Since vegetable tanning generally produces leathers which are fuller, plumper and more easily tooled and embossed, leather tanned by the chrome method is sometimes retanned in vegetable tannins.

- Coloring is accomplished by placing hides in a drum with natural or synthetic dyes.
- Fat liquoring involves the addition of oils to replace natural oils lost in the beamhouse and tanhouse processes and to make the leather pliable.

Waste materials from the retan, color and fat liquor processes include:

- Dissolved organic solids
- Dissolved inorganic solids
- Chromium
- Dyes.

4. Finishing

Finishing operations include drying, coating, staking, and plating. These provide only a minor contribution to the liquid waste.

(2) General Processing Trends and Projections

Technological change has been relatively slow in the tanning industry in comparison to many other industries. Table A-7-1, giving past, present, and projected trends in the subprocesses employed by the industry, shows relatively little expected change over the next 10 years. With respect to the major sources of waste effluents, the projected increase in lime

Table A-7-1
Subprocessing Trends in the Tanning Industry 1950-1982*

Production Process and Significant Subprocesses	Estimated Percentage of Plants Employing Process				
	1950	1963	1967	1972	1982
Storage & Trimming of Cured Hides					
Air drying	10	0	0	0	0
Salting	70	60	50	40	40
Salt & Air Drying	20	20	20	20	20
Brine Curing	0	30	80	85	90
Washing & Soaking	100	100	100	100	100
Soak or Green Fleshing	70	90	90	80	40
Lime Fleshing	30	10	10	20	60
Re-Soaking	–	–	–	–	–
Hair Saving	60	45	45	45	45
Hair Pulping	40	55	55	55	55
Bating & Pickling	100	100	100	100	100
Tanning					
Vegetable	30	20	20	20	20
Chrome	70	80	80	80	80
Synthetic or Resin	-	-	-	-	-
Retanning					
Vegetable	70	75	70	60	45
Mineral	5	5	5	5	5
Syntan & Resin	15	20	25	35	50
No Retan	10	0	0	0	0
Coloring	80	90	90	90	90
Bleaching (Hypo, oxalic + syntans)	45	35	35	35	35
Fatliquoring	80	90	90	90	90
Stuffing (Hot Drum Method)	20	10	10	10	10
Filling & Pigmenting in the Drum	70	80	85	85	95

*Environmental Protection Agency data.

fleshing would add to the waste streams in the beamhouse operation. Table A-7-2 indicates that little can be gained to reduce pollution from implementation of available alternate production processes.

(3) By-Product Utilization, Waste Recovery, and Recycling

There are recognized markets for several of the by-products of the tanning industry. For example, fat is used in glue manufacturing, hair is used in brushes or upholstering and rug backing, spent tanbark is used for special purpose floor coverings for horse shows, circuses, etc. In addition, there is also a certain amount of recovery and recycling of wastes such as degreasing liquors and chrome tan liquors.

Often the decision to save a by-product or recover a waste material for reuse is dependent upon the economics of the situation. For example, the recent low market price for hair has not made it profitable for tanneries to save hair in the beamhouse operations. Consequently, more tanneries use "pulping" or "burning off" which completely destroys the hair. In general, recent trends in the tanning industry are toward less waste recovery and by-product utilization. Table A-7-3 details normal by-product utilization in a tannery.

Table A-7-2
Pollution Reduction Efficiency of Alternate Tanning Subprocesses*

Fundamental Process and Alternate Subprocess	Pollution Reduction Efficiency (%) Vol	BOD	SS	TDS	Remarks
Wash & Soak					
Long (overnight soak)	0	0	0	0	Most plants report no difference in pollution generated.
Short (short soak)	15	17	15	15	
Unhair					
Pulp hair	0	0	0	0	Which process used depends upon demand for hair.
Save hair	0	25	30	30	
Bating					
Paddle machine	0	0	0	0	Most plants report no difference in pollution generated.
Drum machine	20	10	10	10	
Pickling					
Paddle machine	0	0	0	0	No significant pollution generated.
Drum machine	10	0	0	10	
Tanning					
Chrome	0	0	0	0	Not really alternate methods since they produce a different kind of leather.
Vegetable	90	75	50	80	
Finishing					
A tremendous variety of methods used. Pollution from finishing generally not significant.					

Note: Pollution reduction efficiencies shown are generally the highest reported.

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*Environmental Protection Agency data.

Table A-7-3
By-Product Utilization in the Tanning Industry*

Item	Use
Trimmings - Bellies	Used for edible purposes.
Others	Oil production after rendering. Protein feed after rendering. Gelatin manufacture.
Hair	Used in manufacturing, upholstering, and rug backing.
Fleshings	Glues.
Degreasing Exhaust Drum Liquors	Reuse of solvent in tanning. Soap.
Spent Lime Liquors	After settling, the sludge can be mixed with other plant wastes and sold as fertilizer.
Pickle Solution Wastes	In the past this solution has been reused within the tannery for pickling a number of times. However, tendency of late has been to omit this reuse through advent of drum bate, pickling, and chrome tanning.
Chrome Tan Liquors	Holding and reusing in tannery. Precipitating the $Cr (OH)_3$, filtering, redissolving chromium with H_2DO_4. Most tanners consider this economically impractical.
Spent Vegetable Tans	Evaporated and sold as boiler compounds.
Spent Tanbark	Used as floor coverings for horse shows, circuses, playgrounds - sometimes used in paperboard manufacturing or in making white lead.

*Environmental Protection Agency data.

(4) Tannery Effluents to Air and Water

Identifiable wastes in the tanning industry are presented in Table A-7-4.

4. WASTE DISPOSAL PROCESSES AND PRACTICES

The tanning industry has long been recognized as a major contributor to water pollution because of the high concentrations of organic and inorganic substances presented in untreated tannery effluents. A detailed investigation of the U. S. tanning industry in 1965-66,revealed that,although a number of tanneries were served by various treatment procedures,no tannery had installed a treatment system that was completely satisfactory. Subsequent to this investigation, however, a considerable number of studies and several resulting pilot-scale and full-scale waste treatment systems have been installed and tested.

(1) Current Waste Treatment Processes in the Tanning Industry

Current waste treatment processes in the tanning industry can be grouped into two areas: wastewater treatment processes, and sludge handling and disposal. In general, tanning industry wastes originate as wastewater which, after certain treatment, yields a waste sludge. Both water and sludge processes are listed in Table A-7-4.

Table A-7-4
Current Waste Treatment Processes in the Tanning Industry

Wastewater Treatment Processes

Screening
Plain Sedimentation
Neutralization (incl. Equalization and pH adjustment)
Coagulation (chemical)
Lagoons (aerobic and anaerobic)
Lagoons (holding)
Activated Sludge
Trickling Filtration
Equalization - beamhouse and tanhouse wastes
Biological Oxidation
Flue Gas and Precipitation with Resins
Polyelectrolyte Treatment and Clarification - lime wastes from beamhouse
pH Adjustment (sulfuric acid, lime)
Flocculation, Double Settling and Equalization Evaporation of Tan Liquor

Sludge Handling and Disposal

Landfill
Digestion; Liquid Sludge to Land Irrigation
Digestion; Sludge to Lagoons
Digestion; Vacuum Filtration, Flash drying; Landfill
Vacuum Filtration
Incineration

(2) Advanced Treatment Systems for Tannery Wastes

Advanced treatment is concerned with the removal of one or more specific contaminants to a lower level than afforded by secondary treatment. Advanced treatment for tannery wastes should be directed toward the reduction of the following:

- Suspended and colloidal solids
- Organic materials
- Dissolved inorganics
- BOD and COD
- Color.

The following techniques have been used in other industries through the application of several physical and/or chemical processes; however, these processes have not been directly applied to tannery wastes:

Suspended and Colloidal Solids Removal

- Flotation and skimming
- Filtration
- Micro-straining
- Coagulation - flotation.

Dissolved Solids Removal

- Activated carbon
- Ion exchange
- Reverse osmosis.

Certain of these processes may be required when effluent levels, subsequent to secondary treatment, are unsatisfactory for discharge to streams which have extended low flow periods or which receive wastes from a highly industrialized area. In this case, it may be desirable to reduce certain effluent parameters to the lowest level technically feasible.

(3) Composition of Waste Streams and Efficiency of Waste Treatment Processes

Some of the more important characteristics of the individual waste streams are identified in the following table:

Waste Fraction	Flow (tgpd)*	COD (mg/l)	Suspended Solids (mg/l)	pH
Wash Water	25	2100	1300	6.8
Soak Water	10	2200	1000	7.8
Lime Water	10	11900	30300	12.3
Rinse Water	20	2500	4900	12.3
Hair Water	15	2500	3100	12.3
Fleshing Water	5	3600	4900	12.3
Bate Water	55	1700	1000	9.0
Spent Tan Liquors	60	10000	500	4.5

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* 1 tgpd = 3785 liters per day or 1,000 gal/day

As shown above, lime vat, rinse vat, and hair washer waters contain moderate to high concentrations of COD and suspended solids (mostly $Ca(OH)_2$), and have a high pH; yet they make up only 32 percent of the beamhouse wastewater volume. The wash, soak, and vating waters represent 64 percent of the waste volume, but are moderate to low in COD and suspended solids, and near neutral in pH.

There is a significant variation in reported efficiencies of various treatment processes. With respect to individual pollutants, some processes inherently contain more effluent than others. However, treatment efficiencies are also highly dependent upon the differences in pollutant concentrations arising from different production subprocesses.

Typically reported treatment removal efficiencies are presented in Table A-7-5. In actual practice, several individual treatment processes are combined in most treatment installations.

(4) Extent of Waste Treatment in the Tanning Industry

Available data waste treatment practices in the tanning industry, indicates that relatively little effective treatment has been attempted until the past several years. Typically, tanning wastes are discharged into a municipal sewer system which provides secondary waste treatment, when available.

Table A-7-5
Waste Treatment Processes and Process Efficiencies*

Item	Normal Pollutant Reduction Efficiency (%)				
	BOD	SS	Color	Chromium	Sulfide
In-Plant Treatment					
Screening	5	5-10	0	0	0
Equalization in Holding Basins	0	0	0	5-10	0
Sedimentation	25-62	69-96	5-10	5-30	5-20
Chemical Coagulation	41-70	70-97	6-90	50-80 Est.	14-50 Est.
Lagoons	70	80	25 Est.	10-20	0
Trickling Filtration	65-80	85-90	15-70	25-75 Est.	75-100
Activated Sludge	85-95	80-95	75 Est.	75 Est.	75-100
Sludge treatment by: Lagoons Digestion Vacuum filtration Incineration					
Municipal Treatment					
Primary	20-54	14-75	20 Est.	20-25	10-15
Primary and Trickling Filtration	85-95	80-95	25-75 Est.	25-75 Est.	75-100
Primary and Activated Sludge	75-95	77-95	75 Est.	75 Est.	75-100
Primary and Chemical Coagulation (lime)	50-90	73-96	90 Est.	50-90 Est.	75-100 Est.

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*Environmental Protection Agency data.

Approximately 45 percent of wastes are not treated before discharge into stream, lakes or ocean.

Results of recent waste treatment surveys are presented in Table A-7-6. The Eye survey of 1967 (Reference 2),represents about 95 percent of the total industry based upon total leather production. This survey indicates that screening and plain sedimentation are the most widely utilized waste treatment practices. Holding lagoons are also fairly common. However, such processes as neutralization, coagulation, aerobic and anaerobic lagoons, and activated sludge are utilized by less than 10 percent of the industry.

Current trends in waste treatment indicate that tanneries are relying increasingly on municipal waste treatment facilities for effective secondary treatment. This is evident from the following data on years and percent of tannery discharge into municipal sewers:

	1950	1963	1967	1972
Percent	60	70	75	80 (est.)

Table A-7-6
Waste Treatment Survey*

	Eye, 1967		Stanley Consultants, 1971	
	No.	%	No.	%
Questionnaires Returned	129	100	43	100
Wastes Discharged to:				
Municipal Sewer	82	63	24	56
Stream or Lake	43	33	6	14
Ocean	3	2	0	0
Wastes Currently Are:				
Treated Before Discharge	36	28	7	16
Treated with Municipal Wastes	47	36	5	12
Discharged Untreated	59	45	20	47
Treatment Practices:				
Screening	56	43	11	26
Plain Sedimentation	62	48	8	19
Neutralization	NA		3	7
Coagulation	12	9	1	2
Lagoons (Aerobic and Anaerobic)	11	9	3	7
Lagoons (holding)	35	27	1	1
Activated Sludge	None		1	1

NA = Not Available.

***Environmental Protection Agency data.**

(5) Estimates of Waste Production

1. Net Wasteload Quantities - 1963

The net waste quantities are equal to the gross quantities produced, less the pollution removed by industry-operated and municipally-operated waste treatment facilities. For the base year, 70 percent of the waste volume was treated by municipal facilities, with an average pollution reduction of 80 percent. About 20 percent of the waste volume was completely treated by industry-operated facilities, with an average pollution reduction of 62 percent. On this basis, net pollution reaching watercourses, in 1963, from the tanning industry approximated:

Waste Item	Gross Produced (million lb)	Percent Removed	Net Discharged (million lb)
BOD	150	67.5	49
SS	425	79.5	87
TDS	650	38.0	403

2. Projected Net Wasteload

The quantity of pollution load reaching the nation's watercourses from the tanning industry is expected to decrease in the future. This will result from slightly reduced gross pollution produced, a larger percentage of waste treated, and increased removal efficiencies of waste treatment methods. The net wasteloads are projected through the year 1982, as follows:

Year	Waste	Gross Produced (million lb)	Percent Reduced	Net Wasteload (million lb)
1967	BOD	160	69.0	50
	SS	440	81.0	84
	TDS	670	38.0	415
1968	BOD	160	69.5	49
	SS	440	81.5	81
	TDS	670	38.0	415

(Continued)

Year	Waste	Gross Produced (million lb)	Percent Reduced	Net Wasteload (million lb)
1969	BOD	160	70.0	48
	SS	440	82.0	79
	TDS	670	38.0	415
1970	BOD	155	70.5	46
	SS	430	82.5	75
	TDS	660	38.0	409
1971	BOD	155	71.0	45
	SS	430	83.0	73
	TDS	650	38.0	403
1972	BOD	155	71.5	44
	SS	430	83.5	71
	TDS	650	38.0	403
1977	BOD	150	74.0	39
	SS	420	86.0	59
	TDS	640	40.0	384
1982	BOD	145	77.0	33
	SS	410	89.0	45
	TDS	630	45.0	347

3. Gross Wasteload Projections

Future gross wasteloads are projected below on the basis of projected growth of the industry and anticipated improvement in technology.

Year	Volume (billion gal)	BOD (Million lb)	SS (Million lb)	TDS (million lb)
1963	16.0	150	425	650
1967	16.2	160	440	670
1968	16.2	160	440	670
1969	16.2	160	440	670
1970	16.1	155	430	660
1971	16.0	155	430	650
1972	16.0	155	430	650
1977	15.0	150	420	640
1982	14.0	145	410	630

The previous predictions are based on the assumption that:

- The trend toward hair pulping will continue
- Beamhouse operations will be slowly transferred to the slaughterhouse
- Water reuse and waste segregation will be increased
- The value added in manufacturing projections by Federal Water Pollution Control Administration are accurate.

4. Seasonal Variations

Based on industry information available, there is no significant seasonal variation in hides tanned. In the winter and spring, however, the hides processed tend to be dirtier and have more hair and fat. This increases, slightly, the pollution load per hide processed.

When industrial wastes are combined with municipal wastes, waste removal problems include compatibility and pretreatment. Odors and clogging of sewers, due to pieces of fat, hair, and precipitated lime, are major nuisances. Toxicity of chromium and sulfide ions in biological treatment has also been of concern in combined treatment. High pH values resulting from beamhouse operations may inhibit biological treatment of combined wastes. Large quantities of suspended solids overload primary units and clog secondary units. Excessive grease often creates problems with skimming devices and small nozzle distribution systems.

It is feasible to treat this industrial waste in an adequately designed and operated municipal wastewater treatment plant. Screening, flotation, and neutralization (under some situations) are necessary pretreatments.

REFERENCES

1. Industrial Wastes, W. Rudolphs, Library of Engineering Classics, p. 152.

2. "Survey of Waste Management Practices in the Tanning Industry," D.J. Eye, Proceedings of the Fifty-Second Annual Meeting, Tanners' Council of America, October 1968.

3. Effluent Requirements for the Leather Tanning and Finishing Industry, Stanley Consultants, Inc., for the Environmental Protection Agency, Water Quality Office, September 1971.

APPENDIX A-8

SIC 32—STONE, CLAY, GLASS, AND CONCRETE PRODUCTS

SIC 329—ABRASIVE, ASBESTOS, AND MISCELLANEOUS NONMETALLIC MINERAL PRODUCTS

1. ECONOMIC STATISTICS

Stone, Clay, Glass, and Concrete Products is the title for Standard Industrial Classification Major Group 32. At the three-digit SIC code level, the area of this industry which is of primary concern is SIC code 329, Abrasive, Asbestos, and Miscelleanous Nonmetallic Mineral Products. Further, at the four-digit level, the following codes are of concern:

SIC 3292—Asbestos Products

SIC 3293—Gaskets, Packing and Asbestos Insulations.

SIC code 3292 includes those establishments primarily engaged in manufacturing asbestos textiles, asbestos building materials (except asbestos paper, included under SIC 2661), and other commodities composed wholly or chiefly of asbestos, except those covered by SIC 3293 described on the following page.

SIC code 3293 includes those establishments engaged in manufacturing packing for steam, water, and other pipe joints; for engines, air compressors, etc.; for insulating materials for covering boilers and pipes; and for gaskets. Establishments primarily engaged in manufacturing leather packing are classified in SIC 3121, rubber packing in SIC 3069, and meat packing in SIC 3599.

Mining and milling of asbestos are also considerations for the generation of hazardous waste materials. SIC code 1499 includes those establishments primarily engaged in mining, quarrying, milling, or otherwise in preparing nonmetallic minerals not elsewhere classified, such as asbestos, diatomite, natural gem stones, graphite, greensand, Iceland spar (optical grade calcite), and vermiculite.

(1) Location and Number of Establishments with Value Added

Table A-8-1 shows the distribution of establishments throughout the various states included in the SIC codes being considered. The number of employees and the value added are also given by state.

Table A-8-2 gives the number of establishments in up to ten different size groups for the SIC codes under consideration. The value added is also provided for each size group within each SIC code.

Table A-8-1

Distribution of Establishments and Employees in SIC 32 Subcategories[1]

Industry and Geographic Area	Establishments		Number of Employees (1000)	Value Added By Manufacture (million dollars)
	Total Number	With 20 Employees Or More		
SIC 3292 - Abestos Products				
United States	138	99	21.3	308.1
New England Division	14	11	2.8	34.6
Middle Atlantic Division	32	22	6.7	91.6
East North Central Division	32	21	4.1	62.5
West North Central Division	6	4	0.5	7.8
South Atlantic Division	18	11	2.7	34.8
East South Central Division	4	4	0.3	5.9
West South Central Division	12	10	2.1	33.1
Pacific Division	19	16	1.0-2.499	(D)[2]
SIC 3293 - Gaskets and Insulations				
United States	301	123	18.5	205.5
New England Division	16	8	1.1	13.2
Middle Atlantic Division	78	27	4.1	54.3
East North Central Division	103	47	9.1	94.7
West North Central Division	17	5	0.2	2.6
South Atlantic Division	11	5	0.7	5.1
East South Central Division	8	3	0.3	3.4
West South Central Division	28	14	1.4	15.3
Pacific Division	35	13	1.0-2.499	(D)[2]

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[1] Reference 1.

[2] (D) indicates data has been suppressed to avoid disclosure of individual company information.

Table A-8-2
Distribution of Establishment Size by SIC 32 Subcategories (1)

ITEM	Establishments (number)	Number of Employees (1000)	Value Added By Manufacture (million dollars)
SIC 3292—Asbestos Products			
Establishments, Total	138	21.3	308.1
Establishments with an average of:			
1 to 4 Employees	20	<.05	0.4
5 to 9 Employees	7	<.05	0.5
10 to 19 Employees	12	0.2	2.4
20 to 49 Employees	14	0.4	5.0
50 to 99 Employees	23	1.7	19.4
100 to 249 Employees	36	5.6	84.2
250 to 499 Employees	18	6.1	98.2
500 to 999 Employees	6	7.3	97.9
1,000 to 2,499 Employees	2	(D)(2)	(D)(2)
SIC 3293—Gaskets and Insulations			
Establishments, Total	301	18.5	205.5
Establishments with an average of:			
1 to 4 Employees	79	0.1	2.0
5 to 9 Employees	45	0.3	3.6
10 to 19 Employees	54	0.8	9.3
20 to 49 Employees	54	1.7	21.4
50 to 99 Employees	32	2.3	28.4
100 to 249 Employees	21	3.2	36.2
250 to 499 Employees	11	5.5	53.9
500 to 999 Employees	2	(D)(2)	(D)(2)
1,000 to 2,499 Employees	3	4.6	50.7

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(1) Reference 1

(2) (D) indicates data has been suppressed to avoid disclosure of company information.

(2) Major Raw Materials, Annual Production, and Industry Growth Pattern

The United States is the world's largest consumer of asbestos, using more than one-fifth of the 3.5 million short tons of world's production (in 1968). Approximately 15 percent of the U.S. asbestos required is obtained from domestic production and 85 percent from import. Canada provides about 90 percent of the imported asbestos, and the Republic of South Africa most of the rest. Domestic demand for asbestos, in the year 2000, has been forecast in the range of 1.28 to 1.87 million tons.

Total world production of all grades and varieties, in 1968, was estimated at 3.5 million short tons. Of this total, Canada produced about 46 percent; the U.S.S.R., 25 percent (estimated); the Republic of South Africa, 7 percent; Southern Rhodesia, 5 percent; the United States, 3 percent; and Italy, 3 percent. Canada is expected to continue as the leading free-world producer, but output from other countries should become increasingly significant. In the United States, the demand for asbestos fiber requirements is changing, and the substantial California deposits could reduce the reliance on imports by the year 2000, provided that products from the relatively short fiber receive consumer acceptance. A more remote possibility for a new supply source would be the development of synthetic asbestos production resulting from research by both government and industry.

Asbestos is adaptable to more than 2,000 uses. Because of its high strength-to-weight ratio and resistance to searing temperatures, it is used in rockets and missiles. Asbestos product plants are located in 16 states, principally in the East and South.

About 69 percent of the asbestos consumed goes into the manufacture of asbestos cement products, about 10 percent in floor tile, 7 percent in asbestos paper, 3 percent into friction materials and gaskets, 2 percent in asbestos textiles, 2 percent in paints and caulking, 1 percent in plastics, and 6 percent in miscellaneous other commodities.

The forecast growth rate for the construction industry for total new construction is 4.5 percent. However, the growth rate for asbestos products used in the construction industry is not forecasted to be this great. Asbestos cement products will compete with lumber and other building products, many of which are increasing rapidly in price. The competitive position of asbestos cement products, based on price, is offset in part due to the great dependence on imports to meet demand. Also a variety of new, alternate ceramic and plastic materials are becoming available. In the area of paints and caulking, asbestos also has to compete with an ever-increasing number of new materials. Use of asbestos in floor tile has been increasing in recent years, but,because of the many competing materials,it is not expected to grow at an annual rate of 4.5 percent. Asbestos paper products used in electrical appliances as well as in construction are expected to grow at an accelerating rate, but the quantity of asbestos for such uses is relatively small.

Thus,the demand for use of asbestos in the construction field is forecasted,for the year 2000,at a minimum of 983,000 and a maximum of 1,475,000 short tons. This represents a minimum growth rate of 1/3 of the 4.5 percent,predicted for the construction industry as a whole,and a maximum growth rate of 1/2 of the 4.5 percent forecast base.

Asbestos is an important part of many types of friction materials used in automobiles, trucks, and other transportation equipment. In addition to using asbestos in brake linings, today's automobiles use a super-tough paper containing crocidolite asbestos to cover metal automatic transmission discs. Although the quantity of asbestos in each transmission is small, the output of more than 6 million automatic transmissions annually requires disc paper production in hundreds of tons.

In 1968, almost 11 million linear feet of woven brake linings were manufactured containing asbestos yarn, tape, or cloth. Based on an estimated forecast of the number of motor vehicles produced in the year 2000, approximately four times 1968 production, and on the assumption that the use of asbestos per vehicle will decline to 60 percent of 1968 level, the forecast for asbestos demand in user-operated vehicles, for the year 2000, is 60,000 short tons.

Demand for asbestos in textiles is projected to 56,000 short tons for the year 2000. Asbestos textiles are used in the manufacture of yarn and cloth which is used in safety clothing, packings, brake linings, filters, etc. Carded fibers are 100 percent asbestos, and are used for the clarification of such liquids as beer, wine, oils, and chemicals. Asbestos lap is a felted form of carded asbestos fiber made for the electric wire and cable industry. It is also used as insulation for heater cords, fixture wires and other electrical conductors. Asbestos rovings are used by the electric wire industry as insulation for heater cords, cables, and electrical heating elements. All maritime specifications and many government, industrial, and utility specifications require asbestos cloth to hold insulation in place and to serve as a permanent protection and fireproof jacket over pipe and boiler insulation. Specially-processed lint-free asbestos cloths also serve as protective shields in "clean" areas adjacent to nuclear reactors.

Plastic materials can be reinforced with such different fibers as asbestos, glass fiber, and cotton. Short asbestos fibers are used in the manufacture of such items as handles on cooking utensils, and long asbestos fibers are used in the manufacture of reinforced plastic rocket nose cones. Asbestos phenolic materials are used in aerospace applications. Use of asbestos as a reinforcing material is becoming more significant. The projection for use of asbestos as a plastics-reinforcing material, for the year 2000, is 28,000 short tons. This projection includes the consideration of more use of asbestos in the bodies of automobiles and in phenolic materials for aerospace applications.

On the basis of past performance, it is likely that new uses for asbestos will be forthcoming, and the forecast base of 165,000 short tons for other uses of asbestos in the year 2000 is made on the basis of direct correlation with the GNP growth.

2. DESCRIPTION OF PROCESSES AND WASTE SOURCES FOR ASBESTOS PRODUCTS

Waste sources from asbestos products industries may be divided into three major categories; mining, products manufacture, and product use. Production sources include the manufacture of asbestos textiles, vinyl asbestos tile, asbestos roofing, asbestos-cement pipe and siding (SIC 3292), as well as asbestos packing and insulations (SIC 3293). This report is primarily concerned with the mining and production aspects. The product use, as a source of waste, is widely distributed and random. Therefore, it is excluded from the subject of the study.

(1) Mining and Milling

Asbestos is mined both from open pits and large underground mines. Mining methods vary depending on the type of mine, however, most mines in the United States are the open pit type, and involve either plowing or shoveling to remove asbestos ore. In some cases, blasting is necessary to loosen material. Mined asbestos ore is moved from the mine to storage areas where it remains until it is transferred to a mill for processing.

Asbestos milling is a complex operation involving the separation of chrysotile asbestos from associated massive fractured serphentine, and classification of the asbestos fiber by length into a variety of grades. The process consists, essentially, of coarse crushing, drying, and recrushing in stages, with fiber being removed by air suction or screening at each stage.

Pressure packing processes are used in many mills to pack asbestos fiber under pressure in five-ply paper bags for shipping.

The main form of pollution from asbestos mining and milling operations is airborne asbestos, produced during loading, unloading and moving operations, crushing and mining (especially where blasting is required). Additional airborne asbestos arises from wind-blown dumps, storage piles, and roads made from mine tailings.

No measurements of air pollution from asbestos mines have been made in the U. S. However, foreign studies of air pollution from asbestos mining have found asbestos dust-fall rates ranging from 1.52 grams per 100 square meters per month at a distance of 4 kilometers, to 34.6 grams per 100 square meters per month at a distance of 0.5 kilometers from mining sites. Asbestos dust was observed at distances up to 50 kilometers from sites.

Even though emissions data are not available, an emissions factor of 93 pounds per ton of asbestos has been estimated for mining and milling operations, based on the efficiency of typical emission control systems (see Table A-8-3).

There are no commercial by-products in the production and milling of asbestos. Asbestos fiber makes up only about 5 to 10 percent of the rock mined, and the waste rock consists mainly of broken and pulverized serphentine which is of little or no commercial value. However, practical methods have been devised for recovery of magnesia from waste rock, and small quantities of residual crushed stone have been marketed. In addition, mill waste containing appreciable amounts of asbestos is suitable for use in vinyl flooring.

Emission control equipment is used to some extent in virtually all milling factories. Elaborate ventilation systems have been devised which carry dusty air from emission sources to a variety of dust collection devices, before discharge to the atmosphere. These devices include mechanical dust collectors with or without filter bags, cyclone collectors, bag filters, and bag houses. None of these systems is capable of collecting all of the emitted dust, consequently dust abatement is not complete. An efficiency of 99.5 percent, as reported in Table A-8-3, is the best figure attainable with the present state-of-the-art equipment.

Table A-8-3
Asbestos Emissions Factors for Mining and Milling*

Operations	Uncontrolled	Cyclone	Baghouse	Emission Factor**
Mining	X			3
Loading	X			2
Hauling	X			2
Unloading	X			2
Crushing & Drying		X		10
Milling		X	X	64
Tailings	X			10
				93

* Based on baghouse efficiency of 99.5 percent and cyclone efficiency of 80 percent.

** Pounds per ton of asbestos produced.

Attempts have been made to control dust emissions by covering trucks and storage bins with tarpaulins. However, these inevitably become loose resulting in greatly reduced effectiveness.

(2) Production Processes

In the manufacture of asbestos insulation, asbestos fibers are mixed with magnesium carbonate, wetted, and pressed or slurried in large volumes of water, and then molded by pumping the slurry through porous molds. After molding, the products are cured at high temperatures, then dried, trimmed, and stored.

Wastewater may originate from the slurrying, recycling, curing, and cooling operations. Effluent is alkaline in nature, contains appreciable suspended and dissolved solids, and has relatively low chemical and biological oxygen demands. Treatment of the waste involves sedimentation and neutralization before discharge. Sludge is removed to landfill areas. Sources of airborne asbestos are minimal in the process, however, some may result from grinding the product, and handling the raw fiber.

1. Textiles

During the manufacture of asbestos textiles, raw asbestos fiber is combined with small amounts of cotton or organic fiber such as rayon or nylon, to aid in binding the fiber. After the fibers are thoroughly mixed, they are combed into a parallel orientation by a succession of carding rolls, forming a fluffy blanket. The blanket is then separated into rovings (often with the aid of cotton or organic yarn), and later spun into yarn. The asbestos yarn produced is then woven into a variety of forms. The primary emission from the process is airborne asbestos resulting from blending, carding, spinning and weaving processes, and from the handling of raw asbestos fiber. The largest emissions come from carding and spinning operations.

Efforts to reduce asbestos emissions include extensive ventilating systems connected to blending, carding, and weaving machines, and attempts to keep all raw and finished asbestos material covered with plastic tarpaulin, and wetting yarn before spinning and weaving.

Emissions to air and water resulting from yarn treatment are negligible. The fiber may be treated with aqueous solutions of butadiene or methylmethacrylate to produce a polymer coating during the spinning process. Waste produced in the process other than airborne asbestos encountered in spinning is essentially that resulting from periodic cleaning of treatment troughs to remove deposits of polymer. Yarn is generally wet with dilute sodium nitrite solutions before weaving, but again, waste is minimal. Finished asbestos cloth for use in fireproofing is treated by immersion in tanks containing sodium silicate followed by air or oven drying. Emissions to air and water are again confined to clean-up operations.

The largest uncontolled emission of airborne asbestos probably occurs during textile plant clean-up operations. Dust collecting on lamps, pipes, walls, and virtually all surfaces is periodically removed. In some cases, this involves blowing the surfaces free of dust with high pressure air hoses, followed by sweeping after the dust has settled. Large amounts of asbestos fiber are put into the air, and since the machines are not running, dust abatement equipment is also shut down. Carding, spinning, and weaving machines are also cleaned on a regular basis either by vacuum cleaning and/or air blasting. Dusts and washing wastes usually show up in general plant wastes.

2. Vinyl Asbestos Tile

Asbestos is used as a filler and binder in the manufacture of vinyl asbestos tile.

Raw materials are blended and pressed into sheets, as slabs of flooring compound pass through steam heated colanders. Sheets of tile are then cooled, cut and inspected prior to packaging and storage.

The chief sources of wastewater effluents are condensate and spent cooling water. Air effluents are primarily volatalized organic components set free as the flooring compound is heated in colandering and blending operations.

3. Asbestos Roofing

Asbestos roofing is manufactured by coating asbestos paper with stone granules using asphalt as a bonding agent as depicted in Figure A-8-1. There are no water wastes produced in asbestos roofing manufacture other than cooling water which may contain stone granules.

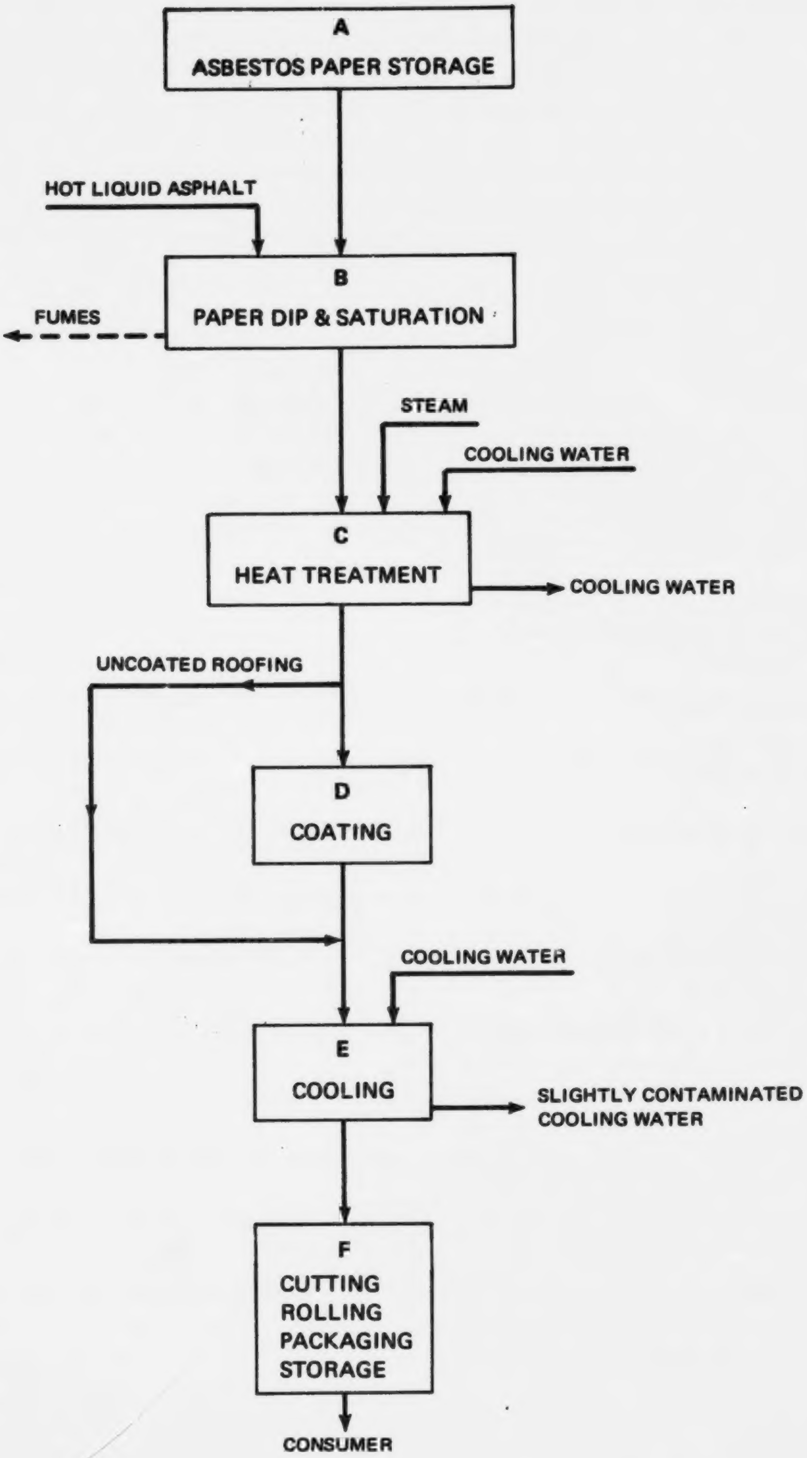
4. Asbestos - Cement Products

Asbestos-cement mixtures containing 15 to 20 percent asbestos and small amounts of other ingredients are used in the manufacture of asbestos-cement siding and pipes.

Asbestos shingles and siding may be manufactured by a dry process where a dry mix is spread evenly on a conveyor belt before water is added, or a wet process where water is added before the material is press-formed.

Conduit manufacture involves a fairly complex series of steps. In one method, a slurry of asbestos-cement mixture with water is collected on a felt-covered belt, and the water is removed by suction. The material is then wound on a rotating metal mandrel to form the pipe. The pipe wall is built to the desired thickness then steam cured. High-density asbestos-cement sheets are made by a press process.

FIGURE A-8-1
Asbestos Roofing Manufacture


A
ASBESTOS PAPER STORAGE
HOT LIQUID ASPHALT
B
PAPER DIP & SATURATION
FUMES
STEAM
COOLING WATER
C
HEAT TREATMENT
COOLING WATER
UNCOATED ROOFING
D
COATING
COOLING WATER
E
COOLING
SLIGHTLY CONTAMINATED COOLING WATER
F
CUTTING
ROLLING
PACKAGING
STORAGE
CONSUMER

Potential sources of wastewaters from the manufacture of asbestos-cement products include effluents from product forming, pressing, finishing, curing, unrecirculated cooling water, and hydrostatic testing.

Waste treatment procedures of asbestos-cement products manufacturing wastes include sedimentation and/or neutralization before discharge or reuse.

5. Gaskets and Packings

Asbestos gaskets and packings are made by treating asbestos ropes woven from asbestos yarn and by pressing asbestos fiber with a suitable binder. Emissions from these processes are minimal, and primarily contained in the fiber handling and textile production operations.

(3) Waste Summation

Wastewater effluents are generally alkaline in nature, containing a relatively high dissolved and suspended solids content, and having minimal oxygen demand. Asbestos in water is not considered to be a significant pollution problem. The main problems arise from alkalinity, temperature, and solids content. Table A-8-4 depicts treated effluent quality from five production sources. The data show that significant volumes of wastewater with high solids content are produced in the manufacture of abestos-cement products, and to a lesser extent asbestos insulations. Wastewater treatment practices include sedimentation, neutralization, chemical coagulation.

Table A-8-4

Effluent Quality - Available Levels of Wastewater Treatment Asbestos Products(1)

Treatment Operations	pH	Suspended Solids lb/ton	BOD lb/ton
ASBESTOS INSULATION:			
Sedimentation	-	0.5	-
Neutralization & Sed'n.	6.5-9.0	0.5	-
Chem. coag. & Sed'n.	6.5-9.0	0.2	-
VINYL ASBESTOS TILE:			
No significant process wastewater			
ASBESTOS ROOFING:			
No significant process wastewater			
ASBESTOS PAPER:			
Sedimentation	-	0.8	-
Neutralization & Sed'n.	6.5-9.0	0.8	-
Chem. coag. & Sed'n.	6.5-9.0	0.3	0.12
ASBESTOS-CEMENT PRODUCTS:			
Sedimentation	-	1.8	-
Neutralization & Sed'n.	6.5-9.0	1.8	-
Chem. coag. & Sed'n.	6.5-9.0	0.8	0.8

(1) Reference 2

The main hazardous emission to air in asbestos mining and processing is asbestos itself. Asbestos is recognized as being responsible for, and/or associated with, a number of pulmonary diseases including asbestosis, pleaural calcification and plagues, cancer of the lung, and mesothelioma of pleaura and peritoneus, both in asbestos workers and in persons living near asbestos factories. Workers using asbestos products have also been reported to have been affected. The main sources of airborne asbestos are mining, milling, and textile manufacture. Other manufacturing processes produce minimal amounts of airborne asbestos.

Present technology used in abatement of asbestos dust include dust prevention techniques by covering exposed asbestos fiber and wet spinning and weaving techniques, as well as the use of elaborate ventilation and dust collection systems. It is unfortunate that it is not desirable to wet a large number of asbestos products.

Dust collection systems consist primarily of suction ventilation systems attached to carding, spinning, blending, etc. machines. Dust laden air is passed through filter material (bag houses) where fibers are easily filtered out since the fibers form a mat which becomes an absolute filter. Cyclone separators are also used in conjunction with bag houses. Dust laden air is pumped into the separator where it is made to follow a circular path, resulting in the sedimentation of the heavier (i.e., larger) particle. Both large and small particle fractions can be extracted, however, only the former are worth recycling.

Both scrubbers and electrostatic precipitators offer possibilities for emission control. Both do not appear to be used extensively, probably due to the cost factors, and the belief that bag houses are sufficiently efficient. It should be noted that attempts to measure concentrations of airborne asbestos in the vacinity of asbestos plants have generally been proved futile with present analytical methods.

REFERENCES

1. 1967 Census of Manufactures, U.S. Department of Commerce, Bureau of Census, 1971.

2. Industrial Waste Study Report, Flat Glass, Cement, Lime, Gypsum and Asbestos Industries, Sverdrup & Parcel and Associates, Inc., for the Environmental Protection Agency, July 1971.

3. Flat Glass Technology, R. Perssons, Butterworths, London, 1969.

APPENDIX A-9

SIC 33—PRIMARY METAL INDUSTRIES

SIC 331—BLAST FURNACES, STEEL WORKS, AND ROLLING AND FINISHING MILLS

This industry comprises establishments primarily engaged in manufacturing hot metal, pig iron, silvery pig iron, and ferroalloys from iron ore and iron and steel scrap; converting pig iron, scrap iron, and scrap steel into steel; and in forming hot rolling iron and steel into basic shapes such as plates, sheets, strips, rods, bars, and tubing. Merchant blast furnaces and by-product or beehive coke ovens are also included in this category.

The remaining industries in the SIC 331 classification produce electrometallurgical products; steel wire drawing and steel nails and spikes; cold rolled steel sheet, strip, and bars; and steel pipe and tubes.

Steel industry literature typically classifies steel mills into four subindustries as follows:

- Fully integrated - Coke ovens, blast furnaces, steel furnaces, and rolling and finishing mills
- Partially integrated (with blast furnaces) - Blast furnaces, steel furnaces, and rolling and finishing mills

- Partially integrated (without blast furnaces) - Steel furnaces and either rolling and finishing mills or a forging department
- Nonintegrated - All other establishments, i. e., beehive coke ovens, by-product coke ovens operated independently of blast furnaces and steel departments, merchant blast furnaces, and establishments with hot rolling and finishing operations.

1. NUMBER AND SIZE OF ESTABLISHMENTS AND GEOGRAPHICAL LOCATIONS

Most of the iron and steel industry in the United States is centered in the integrated facilities of large corporate enterprises. Eight producers are among the 100 largest industrial corporations in this country. The comparatively small integrated producer in this industry represents a very large industrial complex, and even the smallest is, in actuality, not a small operation.

There were a total of 329 establishments in the steel industry (SIC 3312) as of 1967. The majority of these are located in the Middle Atlantic and East North Central geographical divisions (see table on following page).

Division	Total No.	Establishments With 20 or More Employees
New England	8	6
Middle Atlantic	116	94
East North Central	94	79
West North Central	10	6
South Atlantic	24	19
East South Central	28	26
West South Central	9	4
Mountain	3	2
Pacific	37	23
	329	259

The overwhelming majority of steel companies are large employers by general industry standards. In fact, over 90 percent employ over 1,000 persons and over 80 percent employ better than 2,500 persons (see table below).

Establishments	Size (No. of Employees)	Total No. of Employees
39	1-4	(50)
11	5-9	100
20	10-19	300
26	20-49	800
17	50-99	1,300
38	100-249	6,300
40	250-499	14,800
36	500-999	26,500
35	1,000-2,499	57,100
67	2,499 or More	425,900
329		533,100

2. INDUSTRY GROWTH PATTERNS AND PRODUCTION TRENDS

The growth pattern in the steel industry has been rather uneven over the past decade or so. Although there was about a 13 percent increase in the number of establishments, from 288 in 1963 to 329 in 1967, the percentage growth in employment showed considerable fluctuation and was up only 7 percent as of 1967 (see table below).

Year	Establishments	Total No. of Employees (1,000)	Value Added ($ Millions)	Total Tons Prod. (Millions)
1958	291	511.4	6,062.2	85.3
1959	NA	507.5	6,823.4	93.4
1960	NA	550.0	6,844.4	99.3
1961	NA	503.4	6,546.3	98.0
1962	NA	502.2	6,620.9	98.3
1963	288	500.5	7,506.4	109.3
1964	NA	532.9	8,479.6	127.1
1965	NA	565.4	9,379.8	131.5
1966	NA	559.4	9,643.6	135.0
1967	329	533.1	8,910.1	127.2
1968	NA	NA	NA	131.5
1969	NA	NA	NA	142.6
1970	NA	NA	NA	134.9

(NA = Not Available)

Industrial production has also shown considerable fluctuation over the past several years. After steady growth from 85.3 million tons in 1958 to 135.0 million tons in 1966, total steel tonnage has fluctuated from 127.2 million to 142.6 million. These fluctuations can be attributed to variations in supply and demand as a result of the national economy and also vigorous competition from foreign producers.

In summary, it is concluded that the steel industry has entered a stage of transition and consolidation. In the event of a sustained improvement in the national economy and stabilization of the world trade situation, additional growth in steel production is anticipated.

3. STANDARD PRODUCTION PROCESSES AND WASTE MATERIALS

Pig iron is produced in a blast furnace utilizing iron ore, coke, and limestone as raw materials. Steel is produced from pig iron by a variety of processes using the open hearth furnace, basic oxygen furnace, electric furnace, and Bessemer converter. Modern steelmaking processes utilize a large percentage of steel scrap in addition to pig iron and various alloying elements.

The following paragraphs describe the basic processes in the steel industry and identify the waste materials associated with each process.

(1) Typical Manufacturing Processes and Associated Waste Materials in the Steel Industry

For the purpose of describing steel manufacturing and identifying associated waste materials, the steel industry was divided into five sections, each containing several processes and alternate combinations of processes:

- Coke Manufacturing

  Coke
  Coal Distillation Products
  Coal Chemicals

- Iron Manufacturing

  Hot Metal (Liquid Iron)
  Pig Iron
  Iron Castings
  Sinter
  Malleable Iron Products
  Wrought-Iron Products
  Sponge Iron Products
  Slag and Slag Products

- Steel Manufacturing

  Liquid Steel
  Slag and Slag Products
  Ingots
  Steel Castings

- Hot Forming

  Slabs
  Blooms
  Plate
  Hot Band
  Hot Rolled Sheet
  Butt Weld Pipe
  Seamless Pipe
  Structural Shapes
  Hot Rolled Bar
  Billets
  Hot Rolled Rod
  Extruded Steel Shapes

. **Cold Finishing**

Cold Rolled Sheet
Cold Rolled Strip
Tin Plate
Electric Weld Pipe
Cold Drawn Tube
Cold Rolled Bars
Cold Drawn Bars and Shapes
Cold Drawn Wire
Cold Drawn Rod
Nails

(Stainless Steel and Ferro-Alloys Made in Blast Furnaces are in separate categories.)

A given plant may ship iron or steel at any stage of production as its final product, thus giving rise to the general classification previously described (fully integrated, partially integrated, etc.). The basic processes in these five areas and the associated waste materials are presented in diagrammatic form in Figure A-9-1.

Although not strictly a steelmaking operation, coke production is usually included with the industry. This is because it is a heavily used raw material and is produced by most steel plants.

Significant waterborne wastes result from almost all steel mill manufacturing operations. These wastes principally are suspended solids, oils, heated water, acids, plating solution, and dissolved organic chemicals. Steel industry wastewaters

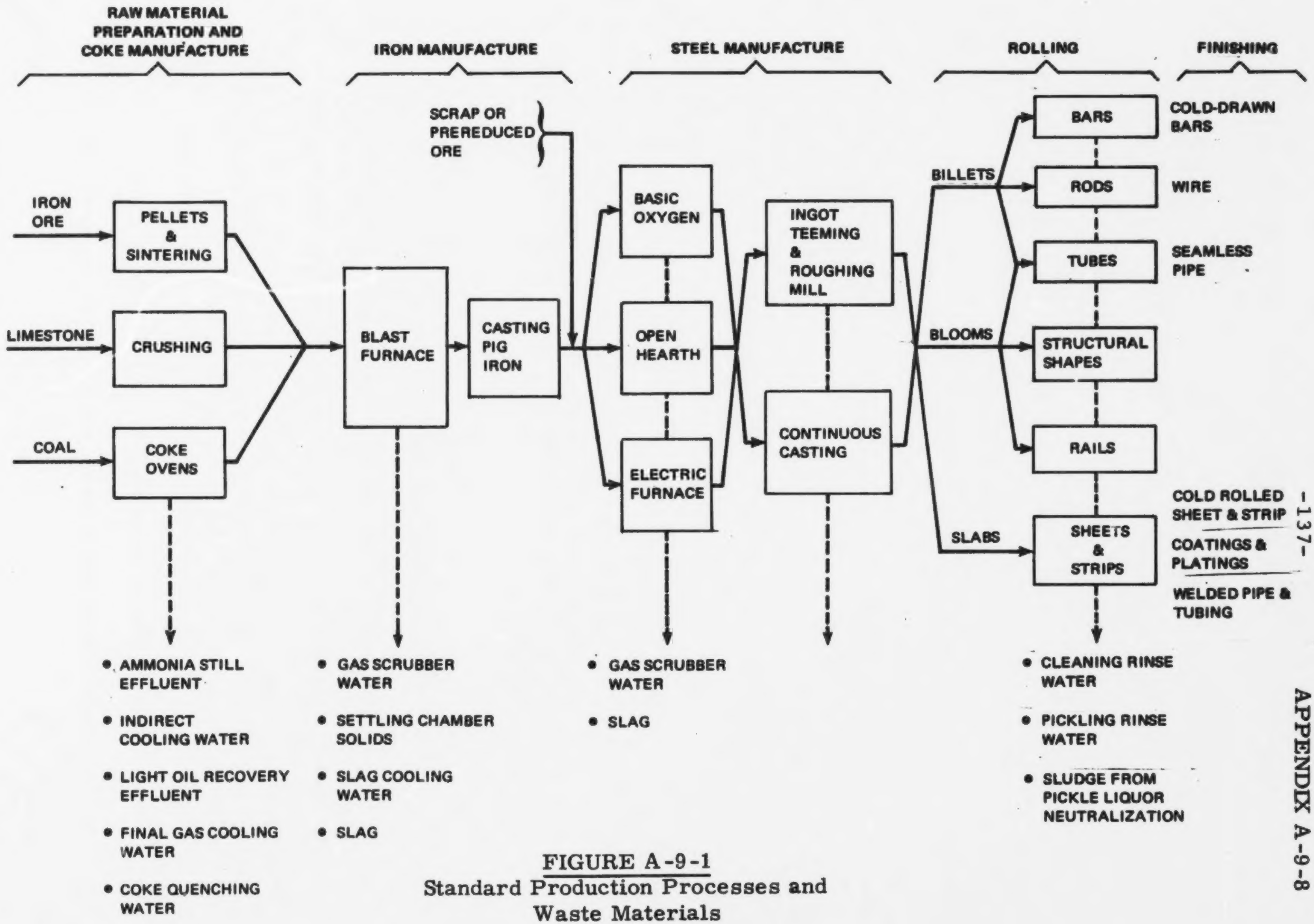

RAW MATERIAL PREPARATION AND COKE MANUFACTURE
IRON MANUFACTURE
STEEL MANUFACTURE
ROLLING
FINISHING
IRON ORE
LIMESTONE
COAL
PELLETS & SINTERING
CRUSHING
COKE OVENS
BLAST FURNACE
CASTING PIG IRON
SCRAP OR PREREDUCED ORE
BASIC OXYGEN
OPEN HEARTH
ELECTRIC FURNACE
INGOT TEEMING & ROUGHING MILL
CONTINUOUS CASTING
BILLETS
BLOOMS
SLABS
BARS
RODS
TUBES
STRUCTURAL SHAPES
RAILS
SHEETS & STRIPS
COLD-DRAWN BARS
WIRE
SEAMLESS PIPE
COLD ROLLED SHEET & STRIP
COATINGS & PLATINGS
WELDED PIPE & TUBING
• AMMONIA STILL EFFLUENT
• INDIRECT COOLING WATER
• LIGHT OIL RECOVERY EFFLUENT
• FINAL GAS COOLING WATER
• COKE QUENCHING WATER
• GAS SCRUBBER WATER
• SETTLING CHAMBER SOLIDS
• SLAG COOLING WATER
• SLAG
• GAS SCRUBBER WATER
• SLAG
• CLEANING RINSE WATER
• PICKLING RINSE WATER
• SLUDGE FROM PICKLE LIQUOR NEUTRALIZATION

FIGURE A-9-1
Standard Production Processes and Waste Materials

are unique among industrial wastes in that the solutions of the effluent streams are so great.

Typical water usage in an integrated steel mill amounts to about 40,000 gallons per ton of steel produced. Water usage is distributed among the various basic operations as follows:

Manufacturing Operations	% of Water Used
Coke	12.5
Iron	25
Steel	12.5
Hot forming and rolling	25
Finishing	20
Sanitary, boiler and other	5

1. Coke Manufacturing

Coke is produced by heating coal to a temperature above which the volatile matter is driven off. In the beehive process, air is admitted to the coking chamber in controlled amounts for the purpose of burning the volatile products distilled from the coal to generate heat for further distillation. In the by-product method, air is excluded from the coking chambers and heat is supplied externally. Today the by-product process produces about 99 percent of all metallurgical coke.

Most materials eminate from the coal volatiles collected as a gas and subsequently cooled by spraying with water. The condensate from the gas and the flushing liquor consist of a tar high in phenols and an ammonia liquor which is stored in stills. Some 90 to 95 percent of the phenols in the ammonia liquor is removed by either the liquid extraction method or the vapor circulation method. Ammonia in the coke-oven gas is recovered by either the ammonium sulfate method or by recovery of anhydrous ammonia. Light oil is scrubbed from the cooled gas by a high-boiling wash oil.

Significant wastes discharged from coke plants include the following:

Waste Material	Compounds and Undesirable Properties
Ammonia still effluent	phenol sulfur ammonia chlorides
Indirect cooling water from coolers and condensers	high temperature
Light oil recovery effluent	phenol cyanide ammonia oil cyanogen
	Final gas cooler water
Coke quenching water (high temperature)	phenol cyanide solids
Coke worf drainage	solids color

2. Iron Manufacturing

Virtually all iron produced in the world today is reduced in blast furnaces. Coke is burned to produce carbon monoxide gas which passes up through the furnace to contact with ore particles (iron oxide). The carbon monoxide gas combines with the ore to produce carbon dioxide gas and metallic iron. The heat generated by the burning coke supplies the heat to make the reaction to proceed and the heat to melt the metallic iron once it is formed.

The major impurity of most iron ore and coke, silica (silicon dioxide), is removed from the furnace by the addition of limestone. At the high temperature in the furnace, the lime combines with the silica to form a low melting material called slag. Melted slag is lighter than the melted iron, thus it can be skimmed off as the iron leaves the furnace.

Slag is treated either by slow air cooling in dry pits in the ground from which it is later dug up as a solid mass or by granulation through rapid cooling from high volume streams of water.

Gases leaving the top of the furnace are hot, dust laden and traveling at high velocities. These are treated by passing through settling chambers, then wet scrubbers and coolers, and in some instances, electrostatic precipitators.

Significant wastes eminating from the iron manufacturing processes include:

Waste Material	Compound
Gas scrubber waste	phenol nitrogen cyanide ammonia suspended solids iron oxide
Slag	sulfides
Gas settling chamber	
Slag cooling water	hydrogen sulfide sulfur dioxide

3. Steel Production

There are three basic methods in use today for the manufacturing of steel:

- Electric Air Furnace
- Open Hearth Furnace
- Basic Oxygen Furnace

The Bessemer converter which was widely used in the past is technologically obsolete and today represents a negligable percent of the steel produced.

All three furnace methods use pure oxygen and/or air to refine hot metal (iron) and other metallics into steel by oxydizing and removing the elements present such as silicon, phosphorus, manganese and carbon. Molten steel from any of the three processes is poured into steel holding ladles and transported either to the teeming or the continuous casting area. Sometimes further processing in the way of further oxidation and alloying is done in the Vacuum Degassing Process area.

Teeming involves pouring the molten steel from the holding ladles into ingot molds for cooling, reheating and then rolling. In the Continuous Casting process, billets, blooms and slabs are cast in water-cooled open-ended copper molds directly from the hot steel.

Waste materials from steel production include slag and various solid and waterborne substances from gas cleaning operations employed in each of the three methods.

The Basic Oxygen and Open Hearth furnaces both utilize precipitation and venturi scrubbers, while the Electric Arc furnace also employs the baghouse. Waste materials are as follows:

Waste Material	Compound
Slag	silicon dioxide manganese oxide phosphorus pentoxide sulfur iron
Gas scrubbing water	oxides of iron sulfur nitrogen oxide suspended solids

(1) Further Processing of Steel

In the hot forming and rolling processes, the steel ingot is generally sent to the blooming or slabbing mill. The basic operation involves the gradual compression of the steel ingot between surfaces of two rotating rolls to form either blooms, slabs, or billets of varying square and rectangular shapes.

The basic purpose of the various hot forming processes is to produce various finished or semi-finished products. These include pipe, structural shapes, bars, rods, and extrusions, among other things.

During most of the hot forming and rolling processes a considerable amount of waste is generated in cleaning and cooling the steel.

Cleaning usually involves the removal of scale and oxides from steel surfaces by pickling in dilute acid solution. In the reduction, forming, shaping and rolling from the initial ingot on through all the hot forming and rolling processes, the wastewater generated includes the following waste materials:

Waste Material	Compound
Cleaning, flushing and pickling rinse water	suspended solids oil iron scale
Sludge from lime neutralization of spent pickle liquor	

(2) Finishing Operations

Finishing operations are usually the final ones in the overall steel manufacturing processes. These include:

- Pickling
- Cold rolling
- Tin plating

- Galvanizing
- Chrome plating
- Cold shaping
- Cold drawing
- Coating of all types
- Tempering
- Polishing

Many of the finishing operations involve special lubricating, cleaning and cooling operations. Lubrication is typically performed by oil or oil and water emulsions. Cooling is done by various water sprays and rinses, and cleaning is usually accomplished by various pickling solutions.

Finishing operations produce wastewaters and other waste effluents. These include the following:

Waste Material	Waste Compound or Undesirable Property
Rolling solutions for lubrication	Oil Suspended solids
Cooling water	Oil Submicron solid particles High temperature
Pickling rinse water	Sulfuric acid Hydrochloric acid Iron salts
Spent acid baths	Sulfuric acid Hydrochloric acid Iron salts
Plating and coating effluent	Tin Chromium Cadmium Zinc Nickel Cyanides Acids Alkali

(2) Production Processing Trends and Projections

The general trend in the steel industry is toward the use of subprocesses which will produce products of lighter unit weight at increasingly higher speeds with minimum manual operations. Production units generally tend toward the largest sizes in order to realize the economy of scale.

1. Effect of Advanced Technology on Volumes of Waste Materials

The application of advanced technology usually produces increased amounts of waste materials. Levels of technology in the industry may be described according to the relative prevalence of certain subprocesses in a particular plant. New or advanced subprocesses being increasingly employed include:

- Basic oxygen furnace
- Continuous casting
- Vacuum degassing
- Hot scarfing
- Electrolytic tinplating and galvanizing

Plant sizes vary considerably, however, the majority of plants produce less than 1 million ingot tons per year as shown in the following table of 1967 data:

Plant Size	% of Plants	Annual Production (Ingot Tons)
Small	53.9	Less than 1,000,000
Medium	15.2	1,000,000 to 2,000,000
Large	30.9	More than 2,000,000

Generally, the larger plants tend to be the newest and have a higher percentage of advanced technology as demonstrated in the following table using 1968 data:

Plant Size	Level of Technology		
	Old	Typical	Advanced
Small	31.9	53.8	14.3
Medium	30.0	54.8	15.2
Large	27.8	34.0	38.2
All	30.0	46.0	24.0

Waterborne wasteloads tend to be the greatest with the newer plants utilizing advanced technology in order to achieve high-speed high-volume output. This is generally due to the fact that wastes are generated in proportion to the surface area of steel exposed during the rolling and finishing operation and in proportion to the relative gas-liquid interfacial areas in the iron-making and steel-making operations. The predominance of lighter products and higher production rates tends to maximize these areas and thus generate greater unit wasteloads. Wastewater volume for various levels of technologies is summarized below:

Level of Technology	Gallons Wastewater per Ingot Ton
Old	9,860
Typical	10,000
Advanced	13,750

The newer installations do, however, generally incorporate waste treatment facilities, and actual plant discharges are not necessarily greater in newer plants.

Particularly difficult waste problems arising from the newer subprocesses includes:

- Sub-micron size particles in gas wash water from ferromanganese furnaces

- Very fine suspended particles in wastewaters from basic oxygen furnaces and hot-strip mills
- Soluble oils in effluents from cold mills.

2. By-Product Utilization, Waste Recovery, and Recycling

Conservation and reuse practices are common in many areas of the steel industry due to the sheer magnitude of the waste materials involved. There are obvious economic incentives to recover and recycle certain materials including:

- Coke oven gas
- Blast furnace gas
- Flue dust
- Slag
- Soluble oils
- Mill scale
- Coke oven chemicals
- Scrap iron and steel

However, much of the industry's wasteload is contained within the large quantities of water used in the manufacturing process. Except for a few items listed above, water has not been conceived or reused to a significant degree. In most instances, the sheer volume of wastewater makes recovery and reuse of materials uneconomical. Also contributing to this situation are the facts that the petrochemical industry is highly competitive in the product areas in which recovered materials would fall and also that the industry is geared to heavy high-volume production with raw materials cheap on a weight basis and, therefore, usually uneconomical to recover with expensive processing. Materials which are typically not reclaimed or reused include:

- Pickling acids
- Plating solutions
- Basic oxygen process dust
- Lubricating oils
- Coke oven chemicals
- Neutralized pickle liquor sludge

(3) Waste Materials from the Steel Industry

A comprehensive list of waste materials from steel mills is presented below. Since there is a wide variation in the types of subprocesses employed at any one plant, not all of the wastes would be found at any one plant.

Waste Materials

- Suspended solids
- Phenols
- Cyanides
- Fluorides
- Ammonia liquor
- Lubricating oils
- Sulfuric Acid (H_2SO_4)
- Ferrous Sulphate ($FeSO_4$)
- Emulsions
- Chromium
- Zinc
- Tin
- Ferric Chloride ($FeCl_2$)
- Hydrochloric Acid (HCl)
- Kjeldahl nitrogen
- Nitrates
- Phosphates
- Sulfates
- Aluminum
- Manganese
- Sodium
- Potassium
- Lead
- Cadmium
- Silicon
- Copper
- Nickel
- Iron
- Triocyanates
- Heated Water

Waste Materials

Dissolved organic chemicals
Soluble metals
Pickle liquor - sulfuric or hydrochloric acid
Ammonia still waste (contains phenols)
Gas final cooler water (contains cyanogen compounds)
Chlorides
Sulfides
Slag (silica plus limestone) (fluxes)
Plating wastes
Coating effluents
Scaling solutions (contain oil and suspended solids)
Mill scale.

4. WASTE DISPOSAL PROCESSES AND PRACTICES

The characteristically large volumes of wastes in the steel industry makes for difficult waste control problems. A waste stream flowing at 10,000 to 25,000 gallons per minute, presents a very difficult treatment problem. Nevertheless, there are a large number of waste treatment processes employed,to varying extents,throughout the steel industry.

(1) Current Waste Treatment Processes

Table A-9-1 presents a list of the many treatment processes currently being employed in the steel industry.

Table A-9-1
Waste Treatment Processes and Materials

	Waste Treatment Processes	Waste Material
Coke Mfg.	Liquid extraction and distillation	Phenol, Cyanide, BOD Ammonia
	Solvent extraction	
	Vapor recirculation and stream distillation	
	Biological oxidation	
	Free or Fixed Ammonia Still	
Iron	Thickening and sintering	Suspended solids in water from gas cleaning process water
	Chemical addition	
Steel	Chemical coagulation	Gas cleaning wastewater
	Magnetic agglomeration	
	Slag processing - iron reclamation and crushing slag into saleable product	Slag
	Chemical Addition	Process waters
	Thickening	
Hot Forming	Scale Pit (settling chamber)	Scale
	Oil skimming	
	Secondary settling	
	Filtration	
Cold Finishing	Haul out	Pickle acid
	Deep well	
	Neutralize	
	Regenerate (HCl only)	

Table A-9-1 (Continued)

	Waste Treatment Process	Waste Material
General	Stabilization lagoons	
	Ion-exchange	
	Dialysis and electrodialysis	
	Fluid bed regeneration	Pickle liquor
	Pressurized deep bed filtration (i. e., Pressure Filtration)	Scale pit water Plate mill waste
	Flocculation and clarification	Hot mill waste
	Coagulation (chemical)	Sinters, oil, sediments
	Chemical precipitation	Scrubbing water
	Filtration, quartz sand filter	Waste waters
	Dissolution, carbon adsorption, solvent extraction chemical precipitation	Nickel, cobalt, molybdenum chromium (super alloy grindings)
	Biological digestion and sludge activation	Coke sludge
	Benzine-NaOH-dephenolization	Phenol
	Phenosolvan process	Phenol
	Ifazol process	Phenol
	Electrolytic decomposition	Phenol
	Fractionation	Phenol (recovery)
	Activated sludge	
	Vaporization by steam	
	Extn. by steam	
	Absorption by solids	
	Deep-well	Acid
	Pickling, crystallization and recovery	
	Liquor regeneration	

(2) Advanced Treatment Systems

Just about any known waste treatment process, which is applicable to the steel industry, can be found in operation in one place or another. Therefore, rather than looking toward any vastly new treatment processes on the horizon, the steel industry is largely attempting to improve the operations and economies of systems presently in use. Some of the more advanced systems include the following:

- Phenols - A solvent extraction system is reported to yield 99 percent recovery
- Acids - Lime neutralization with solids separation and recovery of iron oxide is being utilized by some companies. There are also several proprietary systems being marketed for acid recovery including:
    - A sulfuric acid recovery system has been developed by KSF Chemical Processes Ltd.
    - Hydrochloric acid recovery systems on the market include the Turbulator System, Dr. C. Otto and Co., Bochum, Germany, and the Fluid Bed Regeneration System, Lurgi Gesellschatt, Frankfort, Germany.
- Oily wastewater treatment systems include equalization, chemical addition with rapid mixing, flocculation, and dissolved air flotation all employed in sequence.

(3) Composition of Waste Streams and Efficiency of Waste Treatment Processes

Waste streams from steel plants contain considerable numbers of types of waste materials. These waste materials will vary in quantity and type depending upon several factors such as:

- Level of technology employed in each subprocess
- Subprocesses used
- Types of products being manufactured
- Proper operation of facilities
- Waste treatment systems employed

Total wasteloads and wastewater volumes per unit of product for typical waste materials is presented in Table A-9-2.

Estimated wasteloads and wastewater volumes for 1968 in terms of millions of pounds and pounds per dollar value added are given in Table A-9-3.

Table A-9-2
Estimated Waste Loads and Volumes

Wasteload, Pounds Per Ingot Ton Per Day

Wastewater, gals per ingot ton per day	Old Technology	Typical Technology	Advanced Technology
Suspended Solids	103	125	184
Phenols	0.069	0.064	0.064
Cyanides	0.029	0.028	0.031
Fluorides	0.033	0.031	0.031
Ammonia	0.082	0.078	0.078
Lube Oils	3.08	2.72	2.37
H_2SO_4	3.03	3.54	2.83
$FeSO_4$	11.3	13.2	10.5
Emulsions	0.332	0.414	1.17
Chromium	-	0.063	0.063
Zinc	-	-	0.0025
Tin	-	0.016	0.016
$FeCl_2$	-	-	2.10
HCl	-	-	0.565

Wastewater volumes on a similar basis are tabulated below:

Technology Level	Wastewater, gals per ingot ton per day
Older	9,860
Typical	10,000
Advanced	13,750

Table A-9-3

Wastewater Loads and Volumes for Typical Waste Materials

Estimated Wasteloads and Wastewater Volumes in 1968

Technology Level	Old	Typical	Advanced	Totals	Waste Loads and Wastewater Volumes Per Million $ Value Added
Ingot Tons/Year	41.5×10^6	63.7×10^6	33.3×10^6	138.5×10^6	
Wastewater, Gals./Year	409×10^9	637×10^9	458×10^9	$1{,}504 \times 10^9$	1.37×10^8
Waste	Waste Loads in Millions of Pounds Per Year				
Suspended Solids	4,270	7,960	6,120	18,350.00	1,668,000#
Phenols	2.86	4.07	2.13	9.06	824#
Cyanides	1.21	1.78	1.03	4.02	365#
Fluorides	1.37	1.97	1.03	4.37	397#
Ammonia	3.40	4.96	2.61	10.97	997#
Lube Oils	128	173	79.0	380.00	34,545#
H_2SO_4	128	225	94.2	445.20	40,473#
$FeSO_4$	469	841	349	1,659.00	150,818#
Emulsions	13.8	26.4	38.9	79.10	7,191#
Chromium	-	4.01	2.11	6.12	556#
Zinc	-	-	0.08	0.08	7.2#
Tin	-	1.02	0.53	1.55	141#
$FeCl_2$	-	-	69.9	69.90	6,354#
HCl	-	-	18.9	18.90	1,718#

The normal waste removal efficiency for various waste treated by a particular waste removal process is presented in Table A-9-4. Projected net wasteloads for 1970 and 1974 (Table A-9-5) indicates that, in spite of increased percentages of waste reduction, waste discharge at steel mills will increase. This is due to the fact that increased steel production by advanced processes will yield considerably larger wasteloads. Better waste reduction will not be able to offset the increased wasteloads.

(4) Current Waste Treatment Practice and Trends

The percentages of steel plants utilizing certain basic waste removal methods is documented in Table A-9-6. General trends indicate an increase in the use of various treatment processes. The more advanced processes including biological treatment, ion exchange, and regeneration are all expected to see more widespread usage throughout the industry.

Pickling liquor wastes and pickling rinsewater appear to be the most troublesome problems plaguing the industry. There appears to be a general trend toward the use of hydrochloric acid, which simplifies regeneration processes, to replace sulfuric acid

Table A-9-4
Efficiency of Waste Removal Processes

Removal Method and Source of Wastes	Normal Removal Efficiency for Indicated Waste					
	Suspended Solids	Lube Oils	Acids	Soluble Metals	Emulsions	Coke Plt. Chemicals
Plain Sedimentation:						
. Blast Furnace & Sinter Plt.	93.8					
. Hot-Rolling Mills	90.7	20.0				
Coagulation & Sedimentation:						
. Plant Furnace & Sinter Plt.	98.2					
. Hot-Rolling Mills	95.4	80.0				
. Cold Mills	50.0					
Recirculation and:						
. Plain Sedimentation:						
- Blast Furnace & Sinter Plt.	98.8					
- Hot-Rolling Mills	96.9	60.0				
- Cold Mills	50.0				75.0	
. Coagulation & Sedimentation:						
- Blast Furnace & Sinter Plt.	99.6					
- Hot-Rolling Mills	98.4	90.0				
- Cold Mills	80.0				95.0	
. Magnetic Separators	80.0					
River Water for Coke Quenching:						
. Blast Furnace						90.0
Still Wastes for Coke Quenching:						
. Coke Plant						92.7

Table A-9-4 (Continued)

Removal Method and Source of Wastes	Normal Removal Efficiency for Indicated Waste					
	Suspended Solids	Lube Oils	Acids	Soluble Metals	Emulsions	Coke Plt. Chemicals
Biological Treatment						80.0
Deep-Well Disposal			85.0	100.0		100.0
Ion Exchange				95.0		
Neutralization & Sludge Lagooning			80.0			
Regeneration Processes			80.0			
Proper Operation of Facilities						

Table A-9-5
Projected Net Wasteloads

	Waste Component	Gross Waste Quantity Generated (lbs)	Percentage of Waste Reduction or Removal	Net Waste Quality Discharged (lbs)
1970	Suspended Solids	$20{,}080 \times 10^6$	93.9	$1{,}223 \times 10^6$
	Lube Oil	401×10^6	40.6	238.2×10^6
	Acids (1)	$2{,}335 \times 10^6$	76.2	554.7×10^6
	Soluble Metals	8.46×10^6	15.5	7.14×10^6
	Emulsions	90.5×10^6	72.3	25.2×10^6
	Coke Plt. Chemicals	25.62×10^6	91.5	2.18×10^6
	Fluorides	4.65×10^6	0	4.65×10^6
1977	Suspended Solids	$27{,}126 \times 10^6$	95.2	$1{,}317 \times 10^6$
	Lube Oil	486×10^6	52.0	233.2×10^6
	Acids (1)	$2{,}909 \times 10^6$	80.7	560.2×10^6
	Soluble Metals	11.25×10^6	34.0	7.42×10^6
	Emulsions	138×10^6	73.5	36.6×10^6
	Coke Plt. Chemicals	32×10^6	91.4	2.75×10^6
	Fluorides	5.80×10^6	0	5.80×10^6

(1) Free and combined acids.

Table A-9-6
Use of Waste Removal Processes

Removal Method and Sources of Wastes	Estimated Percentage of Plants Employing Method				
	1950	1963	1967	1972	1977
Plain Sedimentation:					
. Blast Furnace & Sinter Plant	93	85	80	60	40
. Hot-Rolling Mills	87	78	68	55	40
Coagulation & Sedimentation:					
. Blast Furnace & Sinter Plant	0	4	5	15	25
. Hot-Rolling Mills	0	1	2	5	10
. Cold Mills	0	2	4	6	8
Recirculation and:					
. Plain Sedimentation:					
- Blast Furnace & Sinter Plt.	5	8	10	15	20
- Hot-Rolling Mills	10	15	20	25	30
- Cold Mills	50	65	70	65	60
. Coagulation & Sedimentation:					
- Blast Furnace & Sinter Plt.	2	3	5	10	15
- Hot-Rolling Mills	3	6	10	15	20
- Cold Mills	10	15	20	25	30
. Magnetic Separators	5	10	15	20	30
River Water for Quenching Coke					
. Blast Furnace	80	50	20	10	10
Still Wastes for Quenching Coke					
. Coke Plants	20	50	80	90	90

Table A-9-6 (Continued)

Removal Method and Sources of Wastes	Estimated Percentage of Plants Employing Method				
	1950	1963	1967	1972	1977
Biological Treatment	0	5	10	15	20
Deep-Well Disposal	0	2	5	10	15
Ion Exchange	0	2	5	10	20
Neutralization & Sludge Lagooning	10	50	80	85	75
Regeneration Processes	0	0	2	5	10
Proper Operation of Facilities	20	35	50	60	70

in the pickling processes. However, there is not widespread agreement among the steel producers as to the best treatment of waste pickle liquors. Almost every process including neutralization, deep-well disposal, and regeneration, has its own proponents in the industry.

SIC 333—PRIMARY SMELTING AND REFINING OF NONFERROUS METALS

1. ECONOMIC STATISTICS

Industries in this classification produce primary and secondary nonferrous metals and alloys from ores and concentrates, or from scrap. These industries do not include milling or concentrating operations, since they are located at the mine site and considered mineral operations, rather than manufacturing activities. Industries which process ores to produce chemicals, such as zinc oxide, or which process ores only, such as alumina from bauxite, are also excluded.

Some overlap with other industries is inevitable. Many of the smelters and refineries produce considerable quantities of chemicals, such as sulfuric acid. Others operate their own mines, milling and concentrate plants, or are fully integrated from mine to refinery.

Relatively few establishments are involved in primary metal production; most are involved in secondary processing.

Basic statistics related to these industries (Reference 1) are shown in the following table.

	Employees	Estab. with 20 or more Employees	Value Added
3331 Copper	11,600	32	$ 262,6
3332 Lead	2,700	18	48.3
3333 Zinc	8,100	18	119.5
3334 Aluminum	23,800	24	811.8
3339 Other Nonferrous	7,200	29	139.3
3341 Secondary Smelting and Refining	17,200	182	271.2
Total	70,600	303	$1,652.7

The geographic distribution of these industries is given in Table A-9-7.

The total tonnages involved in this industry are illustrated by the production data in Table A-9-8.

2. PRODUCTION PROCESSES AND WASTES

There are several typical processes involved in the reduction of ores. These typical processes are described first, followed by examples of more specific applications. The wastes associated with these operations are also noted.

Table A-9-7
Geographic Distribution For SIC Code 333

Division	Estab	V. A.(2)	Estab	V. A.	Estab	V. A.	Estab	V. A.	Estab	V. A.	Estab	V. A.
New England	1	--	--	--	--	--	--	--	2	29.1	9	6.7
Middle Atlantic	6	43.3	2	D(1)	D	D	2	D	8		47	82.8
East North Central	3	10.9	4	D	--	-	2	D	4	9.3	60	115.1
West North Central	--	--	3	D	--	--	--	--	--	--	9	
South Atlantic	2	16.0	--	--	--	D	3	450.9	1		10	13.1
East South Central	1	--	--	--	--	--	3		2	75.7	9	13.8
West South Central	2	16.3	3	D	6	43.0	6	253.6	6		12	8.3
Mountain	15	176.1	3	D	D	D	1	228.6	2	20.3	--	--
Pacific	2		3	D	--	--	8		4		24	29.5
Totals	32	262.6	18	48.3	18	119.5	25	811.8	29	139.3	180	269.3

(1) D = Data Withheld
(2) V. A. = Value Added

Table A-9-8
Total Production Tonnage

Product	Tonnage (1000 ST.)
Anode Copper	1030
Unalloyed Copper	1430
Copper Based Alloys	300
Lead Smelter Products	200
Refined Unalloyed Lead	400
Antimonial Lead	280
Babbitt Metal	10
Solder	100
Type Metal	145
Other Lead and Tin Base Alloys	30
Refined Zinc	1235
Zinc Residues	265
Primary Aluminum	5360
Gold	1530 (ounces)
Cadmium	5.3 (1000 ST.)
Nickel	0.2
Alloys	10

These data are approximations only and not sufficiently detailed to identify the sectors which may produce hazardous metallic salts.

Roasting and smelting are traditional means for separating metals from their ores. In recent years, extraction of metal by other processes (such as leaching or extraction from sea water) have become economically feasible. The following paragraphs describe these operations.

(1) Roasting

The roasting operation involves heating with a free or controlled access of air, at temperatures too low for fusion. The objectives may be: the conversion of sulfide ore concentrates to oxide before reduction (perhaps with the expulsion of volatile constituents such as arsenic); or reduction, either with a reducing agent, or to cause a "roast reduction" reaction. Temperature control is often important, however, the thermal requirements vary. Self-supporting roast reactions are said to be "autogenous" (as with zinc sulfide). Control of oxidation-reduction conditions is also important. Sulfur dioxide must be utilized.

The reaction rates of roasting are limited by the supply of oxygen to solid-gas interfaces, and by the escape of gaseous products. Large surface areas, provided by dividing the ore or by concentrating it in thin layers, are necessary for well controlled reactions of adequate rate.

Flash roasting exploits the observation that: in a multiple-hearth roaster, a high proportion of the oxidation takes place when ore falls from one hearth to another. Thus, finely divided zinc sulfide concentrates, injected by air into a combustion chamber, are burnt to oxide. As a result, the heat evolved is adequate to maintain the required temperature.

(2) Smelting

Smelting involves the reduction of an ore (with fusion), at a high temperature attained by the combustion of fuel or consumption of electricity (electrothermal smelting). The object is to segregate the metal required in a separate liquid phase. A flux is added to react with the unwanted material in order to form a fluid slag. Furnace linings of adequate strength and resistance to high temperatures and chemical attack are required. Fluxes, slags and refractories, together form part of the essential chemical problem in a smelting operation.

Fluxes are classified according to chemical type and are chosen in relation to the properties desired in slags. The refractories, essential in all pyrometallurgical processes, are also classified by chemical nature. However, other properties such as resistance to temperature, to temperature changes, to compression and abrasion, as well as to porosity and volume change on firing, are also significant.

(3) Hydrometallurgical Processes

The dissolution and precipitation reactions which are the concern of hydrometallurgy involve handling very large volumes of solutions and of finely divided solids. To secure sufficient extraction in a leaching process, the ore or concentrate must be in a suitable chemical condition for dissolution and must also be in a state of fine subdivision. Some hydrometallurgy applications are given in Table A-9-9.

(4) Specific Applications of General Processes

The following paragraphs describe extraction operations related to specific nonferrous metals and alloys.

1. Copper

The blast furnace was suitable only for high-grade ores and is less adapted to deal with finely divided flotation concentrates. Thus, the reverberatory furnace (Figure A-9-2) is presently used for copper smelting.

Table A-9-9
Applications of Hydrometallurgy

Metal	Source	Preliminary Treatment	Final Treatment
Copper	Oxide ores, azurite ($CuCO_3$ $Cu(OH)_2$) Malachite ($1CuCO_3$ $Cu(OH)_2$) etc.	Leaching with dilute sulfuric acid or ferric sulfate if sulfides present	Electrolysis or "cementation" (replacement by iron)
Gold	Native	Leaching with dilute aqueous sodium cyanide (NaCN) solution	Precipitation by zinc
Magnesium	Sea-water	Precipitation as the hydroxide and conversion to chloride	Electrolysis
Zinc	Sphalerite, etc. (ZnS)	Oxidizing roast, leaching with dilute sulfuric acid	Electrolysis

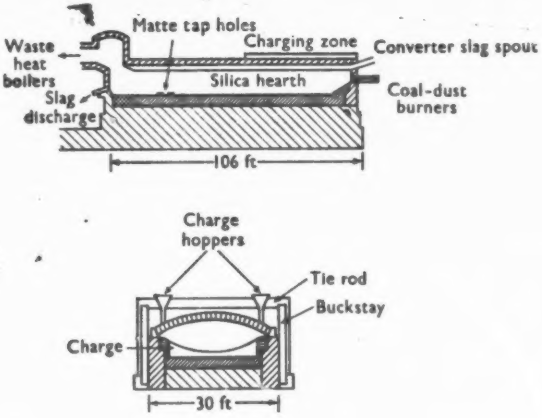

Matte tap holes
Waste heat boilers
Charging zone
Converter slag spout
Silica hearth
Slag discharge
Coal-dust burners
106 ft
Charge hoppers
Tie rod
Buckstay
Charge
30 ft

FIGURE A-9-2
Reverberatory Furnace

Much of the combustion heat is carried away by the waste gases, which leave the furnace at a very high temperature. As a result, waste-heat boilers are an integral part of the furnace.

Converting is the final stage in the smelting process. This is accomplished by blowing streams of air through the molten matter, in a refractory-lined converter in order to oxidize the ferrous sulfide into sulfur dioxide. Thus, the sulfur as a gas is eliminated. About 2 percent of the copper escapes during conversion, but it is recovered by means of a Cottrell precipitator.

The final stage in copper extraction is refining, because all the impurities are contained in the converter product. Figure A-9-3 is a flow chart for copper refining. The modern need is for very pure metal (better than 99.9 percent), for which electrolytic refining is preferable. This technique has the advantage of removing bismuth, selenium, tellurium, and nickel and of leading to the recovery of precious metals. Electrolytic copper refining cell and electrodes are pictured in Figure A-9-4.

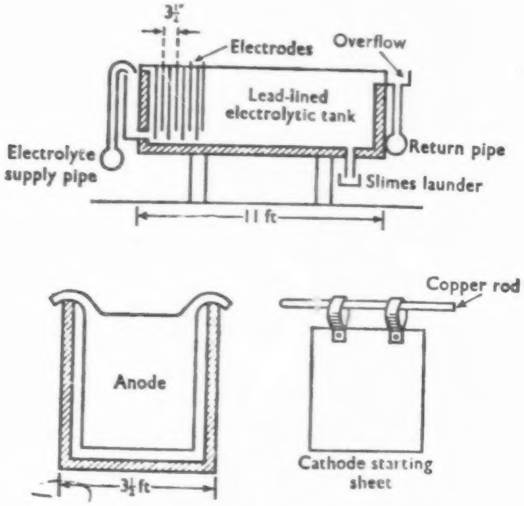
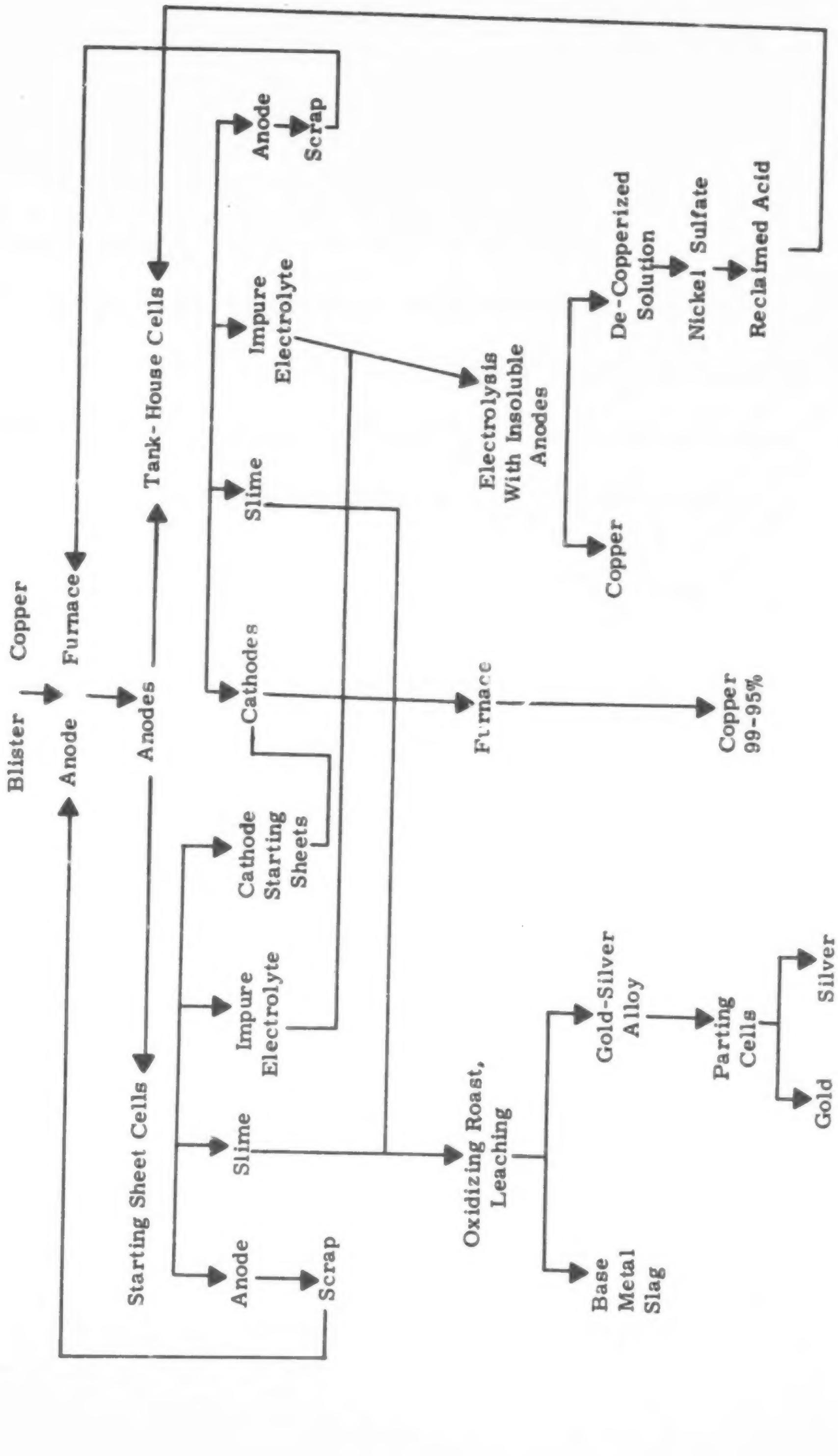

3½"
Electrodes
Overflow
Lead-lined electrolytic tank
Electrolyte supply pipe
Return pipe
Slimes launder
11 ft
Copper rod
Anode
3½ ft
Cathode starting sheet

FIGURE A-9-4
Electrolytic Copper Refining Cell and Electrodes

The purpose of the "slimes launder" is to collect the anode slime, which consists of impurities that are not anodically dissolved and fall to the bottom of the tank.

FIGURE A-9-3
Copper Refining Flow Chart


Blister Anode
Copper Furnace
Anodes
Tank-House Cells
Anode
Scrap
Impure Electrolyte
Slime
Cathodes
Starting Sheet Cells
Cathode Starting Sheets
Impure Electrolyte
Slime
Anode
Scrap
Electrolysis With Insoluble Anodes
De-Copperized Solution
Nickel Sulfate
Reclaimed Acid
Copper
Furnace
Copper 99-95%
Oxidizing Roast, Leaching
Gold-Silver Alloy
Parting Cells
Silver
Gold
Base Metal Slag

Compositions of the slimes vary greatly, but an average analysis might be:

Chemical	Se	Te	Cu	Ag	Au	As	Sb	Pb	N	SO_4
Percent	22.0	3.7	40	10	2.5	0.1	0.2	2	.04	6.2

Large quantities of solid waste material are generated in mining, concentrating, and smelting copper ore (see Appendix A-1 for details). Discharge of obnoxious gases and fumes from smelters is also a problem.

2. Lead

Lead is recovered from its ores by smelting in blast furnaces or ore hearths employing carbon fuels. The sulfur in the concentrates (also containing 70 percent lead and a small zinc content), are removed by a roasting-sintering process, usually on a Dwight-Lloyd sintering hearth pictured below.

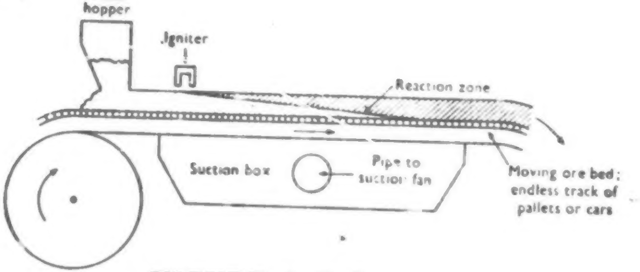

Feed hopper
Igniter
Reaction zone
Suction box
Pipe to suction fan
Moving ore bed; endless track of pallets or cars

FIGURE A-9-5
Dwight-Lloyd Sintering Hearth

Lead recoveries at primary lead smelters are usually about 97 to 99 percent of the lead contained in the ore. Precious metals are recovered in the refining process.

The sequence of processes for softening (the removal of copper, tin, antimony and arsenic) and desilverizing lead bullion, and the recovery of by-products, is subject to many variations. Melting and oxidation characteristics of the impurities determine the method of removal. The high corrosion resistance of lead and its alloys permits a high degree of reclamation.

Lead smelters are equipped with efficient dust and fume collection systems for a 98 percent recovery factor. Smoke purification devices collect sulfur fumes and protective devices prevent lead poisoning. Good ventilation is essential.

3. Zinc

Zinc reduction is accomplished by electrolysis. The zinc concentrate is roasted to eliminate most of the sulfur. Recoveries range from 89 to 98 percent.

Secondary zinc is recovered from copper-base alloys, principally brass. Some scrap is vaporized in a furnace, while other scrap is processed in a retort. A flow chart for lead-zinc production processors is shown in Figure A-9-6.

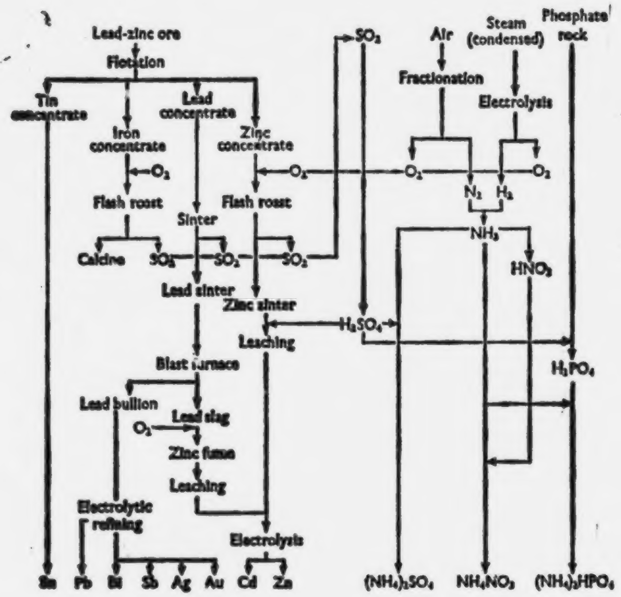

Lead-zinc ore
Flotation
Tin concentrate
Iron concentrate
Lead concentrate
Zinc concentrate
O_2
Flash roast
Sinter
Flash roast
Calcine
SO_2
SO_2
SO_2
Lead sinter
Zinc sinter
Leaching
Blast furnace
Lead bullion
Lead slag
O_2
Zinc fume
Leaching
Electrolytic refining
Electrolysis
Sn
Pb
Bi
Sb
Ag
Au
Cd
Zn
SO_2
Air
Steam (condensed)
Phosphate rock
Fractionation
Electrolysis
O_2
O_2
O_2
N_2
H_2
NH_3
HNO_3
H_2SO_4
H_3PO_4
$(NH_4)_2SO_4$
NH_4NO_3
$(NH_4)_2HPO_4$

FIGURE A-9-6
Lead-Zinc Production Processors

Zinc-base alloys are recovered by remelting and redistillation to be used in commercial zinc products. The copper-base alloys are remelted and the contained zinc is used in brass and bronze ingot.

Efficient dust, fume and stack systems permit collection and utilization of by-products such as lead, cadmium and sulfur. Zinc contained in metallurgical residues, at lead and copper smelters,is mostly recovered and returned to a zinc plant for refining.

4. Aluminum

Most bauxite is refined by the Bayer process. This process involves a caustic leach of bauxite at elevated temperature and pressure, followed by separation of the resulting sodium aluminate solution and selective precipitation of the aluminum as the hydrated aluminum oxide ($AL_2O_3 \cdot 3H_2O$) alumina. The insoluble tailings (red mud) are further treated to extract aluminum silicates. The residuals from this process are known as "brown mud" and are composed of calcium silicates and iron oxides. Primary aluminum is produced by the electrolysis of alumina in a molten bath of cryolite.

Current efficiency ranges from 85 to 90 percent. Energy losses are principally caused by physical losses of metal through spillage and evaporation, and reoxidation of aluminum by carbon dioxide.

To prevent atmospheric pollution, gases are passed through a collecting and scrubbing system which removes alumina, carbon, and fluorides.

A second electrolytic cell (the Hoope cell) produces a superpure aluminum of 99.95 percent purity. At most aluminum plants, solid wastes are impounded in large mud lakes near the plant.

5. Rare Earths

Solvent extraction and ion exchange are the two main commercial methods of separation. Other methods employ fractional crystallization by evaporation, and thermal reactions which include fusion and volatilization.

Technological problems exist in all stages of rare-earth mineral processing. The separation of individual rare-earth elements from one another is difficult because of their chemical similarity. Incomplete reduction and the difficulty of collecting homogeneous metal modules are further problems.

Other nonferrous metals have similar smelting and refining processes as those previously discussed. Specific procedures, as for gold, must be considered. However, the waste disposal problems and practices are usually very similar from one smelting and refining process to another.

3. DISPOSAL PRACTICES

There are many general methods of disposal techniques used in the smelting and refining of nonferrous metals and alloys. There is a general scheme for the disposal and treatment of slag, flue gases, tailings and liquid effluents.

Slag is either trammed to the dump in a molten condition or it is granulated and sluiced away from the furnace. The slag is then delivered to decart ponds, where it settles. Water overflow is collected in settling ponds for the removal of some suspended material. Slag is removed from the ponds and transported to a disposal area where a "slinger" distributes it on the dump.

Flue gases are collected to allow settling of dust, after which they are channeled to a central flue for electrical precipitation and finally released into the atmosphere. Stack emanations have been drastically reduced. Dust removed from the flue system is treated again in the plant. Arsenic and bismuth can be recovered during copper smelting and refining.

Tailings are disposed of in sites adjacent to the slag disposal area. Ponds are used for the storage of tailings.

Effluent from plants contain a high concentration of iron which could pollute streams. Some of the effluent characteristics are:

Flow rate = 3000 to 5000 gpm

pH = 3.5 to 4.0

Fe (iron) content = 2.5 grams per liter

Effluent water is neutralized with lime ($Ca(OH)_2$) to dissolve the iron as ferric oxide ($Fe(OH)_3$). After pH is adjusted to about 7.0, the waters are then released to pond areas.

Dewatering using centrifuges and vacuum filters has been tried for off-site disposal of precipitated wastes. Synthetic organic polyelectrolyte coagulant aids are being recognized as valuable in colloid coagulation. They enhance solid-liquid separation in filtration, clarification, and thickening processes, and are presently under consideration in industrial waste treatment. BOD removals of over 90 percent have been achieved in pilot plants by use of synthetic coagulant aids.

(1) Copper

Copper in solution is highly toxic to aquatic life. Therefore, waste treatment requirements aim for an effluent which contains less than 0.5 ppm copper. Large volumes of copper-free water are used for dilution. Sufficient alkali, preferably lime ($Ca(OH)_2$), is added to raise the pH to near 7.0. However, lime neutralization leads to an increase in the hardness values of the water, and therefore makes it impossible to reuse the water by recirculating it. As a result, a mixture of sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3) is used to maintain a pH in the range 8 to 9. The effluent is crystal clear without the need for settling tanks or clarifiers.

(2) Zinc

Zinc is removed from waste effluent by chemical precipitation and ion exchange (Reference 2). The latter is being used more frequently because it offers the possibility of reclaiming materials for reuse which would otherwise be lost. One of its limitations, however, is the decreased efficiency of the ion exchange resins with repeated use. The ion exchange recovery of zinc is shown in Table A-9-10. In the chemical precipitation, [illegible] of lime results in the precipitation of zinc hydroxide. The efficiency of recovery is dependent upon maintaining an adequate concentration of lime. This process is shown in Table A-9-11.

(3) Aluminum

Solvent extraction is used for recovering alumina from waste solutions. Most of the aluminum is selectively precipitated as crystalline $AlC_3 \cdot 6H_2O$ which is thermally decomposed to produce alumina up to 99.95 percent pure and to recover HCl for reuse.

Table A-9-10
Recovery of Zinc by Ion Exchange

Run #	Total Zn Passed (Mg)	Zn Retained %	Recovery %
1	855	64	99.20
2	900	68	94.10
3	1238	79	64.30

Table A-9-11
Recovery of Zinc by Chemical Precipitation

Lime Added (Mg/1)	pH	Recovery %	Zinc Recovery mg/mg of Lime
0	7	20.4	-----
300	8	96.5	0.868
340	8.5	97.5	0.776
385	9.0	97.8	0.686
425	9.5	99.5	0.632
475	10.0	99.3	0.564

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APPENDIX A-10

SIC 34—FABRICATED METAL PRODUCTS, EXCEPT ORDNANCE, MACHINERY, AND TRANSPORTATION EQUIPMENT

SIC 347—COATING, ENGRAVING, AND ALLIED SERVICES

1. ECONOMIC STATISTICS

This section includes establishments engaged in all forms of electroplating, plating, anodizing, coloring and finishing of metals (SIC 3471), and those engaged in hot dip galvanizing of mill sheets, plates and bars, the enameling, lacquering and varnishing of metal products, and other metal services not elsewhere classified (SIC 3479). The economic data which is shown covers all those activities. The discussion of wastes from this industry is largely concerned with those arising from plating and coating operations.

The two major subsections of the plating and finishing industry are shown below with data indicating the relative size of establishments in this industry group.

	Size of Establishments (No. of Employees)					
	Total	1-4	5-20	20-100	100-500	500-1000
3471 - Plating and Polishing	3241	1237	1149	791	63	1
3479 - Metal Coating	1443	624	470	297	48	3

This data shows that such establishments are primarily shops with few employees. Only the larger establishments are likely to have the capability to design their own disposal systems. The remaining shops must use disposal methods provided by the equipment manufacturers,or not concern themselves with the problems unless economic necessity intervenes. Although the census data indicates less than 5,000 establishments, it is estimated that there are between 15,000 and 20,000 metal finishing facilities in the United States (Reference 1). This industry is found in every community in the country and at every sizable military or other Government operational site.

The value added by this industry,in 1967,was $574.8 million for plating and polishing,and $289.6 million for metal coating and allied services. In 1970,approximately $1 billion was estimated as the annual value added, or contribution to the GNP, of this industry. This is approximately 0.1 percent of the total GNP. While this industry is relatively small, it should be noted that the value of products shipped doubled between 1958 and 1967 in each segment, and more than tripled since 1947.

	Value ($) of Primary Products Shipped		
	1967	1958	1947
3471 - Plating and Polishing	756.1	349.7	172.5
3479 - Metal Coating	404	184.1	60.8

Although wastes from the plating and coating industry are small, in comparison with the volume of liquid wastes generated in other industries, they contain extremely toxic effluents if not properly treated. These constituents are mainly inorganic acids, metals, and cyanides. Good treatment methods are available. However, the statistics on water use within this industry (Reference 2) indicate that less than one-half of the total water discharged was treated prior to discharge.

The effect of these waters on fish is significant. A 100-gallon tank of 50,000 ppm cyanide solution, although diluted by 50 million gallons of water, provides enough cyanide to be toxic to fish. One hundred gallons of chromium plating solution (207,000 ppm Cr), even though diluted by 200 million gallons of water, will provide enough chromate to kill most of the fish food (Reference 3).

2. DESCRIPTION OF METAL FINISHING PROCESSES

The plating and coating industry is comprised of a vast number of metal finishing shops. A variety of metal finishing processes and techniques are employed, depending on the type of finishes produced and the specific methods utilized. Several of the metal finishing primary and auxiliary processes produce wastes, including:

- Primary
  - Anodizing
  - Phosphating
  - Chromating
  - Electroplating
  - Electropolishing
  - Oxidizing and Blackening
  - Electrogalvanizing
- Auxiliary
  - Cleaning
  - Pickling
  - Finishing
  - Rock Stripping.

A brief description of each primary and auxiliary process follows.

(1) Primary Finishing Processes

1. Anodizing

Anodizing involves the production of a nonmetallic oxide coating on metals by means of anode oxidation, i.e., the metal article is treated as an anode in a selected electrolyte. Anodizing baths may contain chromic or sulfuric acids, or a mixture of acids such as a combination of sulfuric and oxalic acids. Anodized surfaces may be finished further by lacquering, staining or other processes. Anodizing must be followed by water rinsing. Commercial coatings of this type are produced on a large scale for aluminum and magnesium, and to a much smaller extent for zinc, titanium, and other metals.

2. Phosphating

Phosphating involves the production of a primarily phosphate coating through immersion of metal articles in an aqueous solution containing metal phosphates. This type of coating is used particularly in "mass production" articles such as automobile bodies and refrigerators. Phosphate coatings can be applied to iron, steel, cadmium, zinc, aluminum, and various other alloys.

3. Chromating

Production of coatings containing chromium (chromating) is accomplished through immersion in chromates, chromic acid, or sulfuric acid solutions. Most metals are chromated in acid solutions; however, aluminum may be chromated in alkaline solutions as well. Primarily, aluminum, magnesium, zinc, cadmium, iron, steel, and nickel are chromated and,to a lesser extent, tin, copper and silver. Special additives are used to promote coating growth, including sulfates, flourides, nitrates, phosphates, or acetates.

4. Electroplating

After precleaning and/or electropolishing, electroplating may be utilized by immersing the article in an appropriate metal plating bath. The composition of this bath depends upon the metal and the specific process used in plating. In general, plating baths contain either alkaline solutions of cyanides (pH10 or above), or acid solutions which include salts of the metal to be plated. Alkaline conditions must be maintained in cyanide baths to prevent liberation of hydrogen cyanide. In plating processes involving cyanide baths, cadmium metal and salts and sodium cyanates and carbonates are used. Cadmium is deposited principally from cyanide baths, but it may be deposited, to a lesser extent, from acid baths. For many metals, both acid and alkaline processes exist for the same metal. Chromium, zinc, and cadmium are among the most commonly plated metals.

5. Electropolishing

Electropolishing, known as "brightening," may be used to provide a final finish or as a treatment prior to electroplating. This process produces a mirror-like finish. Electropolishing is performed electrolytically in baths. These baths may contain sulfuric, orthophosphoric, chromic, nitric, etc., acids depending upon the metal to be polished.

6. Oxidizing and Blackening

Natural protective oxides or hydroxide coatings may be thickened artifically by oxidizing the metal in salt baths or aqueous solutions. A blackened oxide coating can be produced by adding sodium nitrate or nitrite in an alkaline bath.

7. Electrogalvanizing

Zinc plating, or electrogalvanizing, may be performed in acid baths containing zinc sulfate (as a souce of zinc), or from cyanide baths containing sodium and zinc cyanides (under alkaline conditions).

(2) Auxiliary Finishing Processes

Prior to any further finishing, stamped and/or machined items must be cleaned of contaminants. These contaminants consist of oxide coatings, grease, oils, salt film, and other foreign materials. Oxide coatings are removed by "pickling," the dissolution of the coating by immersion in dilute acid baths Grease and oil may be removed by immersion in alkaline baths or by organic degreasing. Waste from these processes include alkalines, unused acids, and salts of dissolved metals.

To prevent contaimination of the pickling and cleaning baths, water rinsing is required between and again after these two stages to prevent contamination of plating and/or finishing baths. In fact, since the majority of finishing operations are accomplished through immersion in baths, cold water rinsing follows every finishing operation. As a consequence, the major source of effluent is the large volume of rinse water contaminated with bath solutions. Only after cleaning is the article ready for a number of different finishing processes (the primary finishing processes discussed earlier), such as anodizing, electropolishing (brightening), electroplating, phosphating, or chromating.

Sometimes, if defective coatings are produced, they are stripped and the coating process is repeated. The type of stripping solutions used depends upon the particular coating that must be stripped. Phosphate coatings are stripped in alkaline solutions of EDTA (a tetrasodium salt) and phosphoric acid. Chromate coatings are usually stripped by using solutions of chromic and phosphoric acids. Racks are used to hold the metal articles during all finishing operations. These racks build up with coatings and plating metals and, therefore, must be periodically stripped.

(3) Typical Metal Finishing Operating Sequence

A specific metal finishing shop may combine any number of the finishing processes previously mentioned. An example of a typical operating sequence would be:

- Mechanical and thermal treatment (grinding, polishing, abrasive blasting, rolling, pressing, turning, etc.)
- Precleaning with solvents, solvent vapors, alkalai or other cleaners
- Rinsing in cold running water
- Pickling in acid solutions or in caustic soda solution (in the case of aluminum)
- Rinsing

- Immersion in coating or electropolishing solutions
- Rinsing in cold water
- Rinsing in hot water with special agents
- Air drying
- Special after treatment such as coloring, oiling, greasing, waxing, or lacquering (Reference 1).

3. WASTE CHARACTERISTICS

Primary sources of waste in plating and finishing operations are as follows:

- Rinse waters from plating, cleaning, and other finishing operations
- Concentrated plating and finishing solutions, intentionally or accidentally discharged
- Waste from plant or equipment cleanup
- Sludge, filter cakes, etc., produced by naturally occurring deposition in operating baths, chemical rinsing circuits, etc.
- Regeneration from ion exchange units
- Water from vent scrubbers.

Most of the available data on the volume and composition of electroplating and metal finishing wastes exist for larger plants. Data demonstrate the wide variation in waste effluent composition from plant to plant (Reference 1). This variation is dependent upon local plant conditions, rinsing techniques, and recovery methods.

Little data are available on the volume and composition of wastes in the smaller finishing shops, especially those that perform general plating. As a result, it is assumed that waste parameters are variable. Burford and Masselli (Reference 4) have presented typical waste concentrations for several different plants, as well as for the same plant but on different occasions.

These source data indicate that finishing effluents have the following properties:

- pH's ranging from 2 to 11.9
- Copper content from 6 to 300 ppm
- Iron content from 2 to 21 ppm
- Nickel content from 0 to 300 ppm
- Zinc content from 0 to 300 ppm
- Hexavalent chromium content from 0.5 to 700 ppm
- Cyanide content from 39 to 1,500 ppm.

These data also demonstrate the waste variability from a given source on different occasions.

In general, total plant waste can range from highly acidic to highly alkaline depending upon the number of baths used and the amount of pickling and stripping done. Effluents from most plants contain high concentrations of toxic cyanide which are used in the many plating processes. Large concentrations of toxic hexalavent chromium are also found as a result of metal plating and the extensive use of chromic acid. A number of other materials such as phosphates, chromates and plating metal salts can be expected. Some plating metal salts are particularly toxic,such as hexavalent chromium, lead and cadmium.

The composition of naturally precipitating metal and processing reagent sludges are not unlike those of the rinse waters, except that they are more concentrated. Generally, these sludges are quite toxic and may be acidic or alkaline as well.

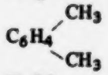
In addition, a number of gaseous and/or airborne pollutants are produced from the metal plating and finishing operation. These are primarily dealt with through the use of scrubbers which are connected to ventilating systems. As a result, those wastes contribute somewhat to the aqueous waste. Information on gaseous and/or aerosol wastes is not readily available. Table A-10-1 listing the limitations on airborne finishing effluents is presented as an indication of the types of materials emitted (Reference 5).

4. DISPOSAL PRACTICES AND TREATMENTS

Ultimately, diluted liquid and solid wastes either must be discharged into public waterways and sewer systems or, in the case of deep well disposal, be hauled away to land fill sites. Reclamation practices exist for extracting plating metals, acids and process water. However, employment of these practices is variable.

Usually, rinse water treatment is necessary before disposal. This is done in order to remove cyanide, hexavalent chromium, oils, greases, acids, alkalies, and other plating metals. The most widely used treatment methods involve chemical oxidation and reduction processes, which remove or convert toxic cyanides and hexavalent chromium. Other widely used methods are processes including evaporation, precipitation, filtration, sedimentation, and ion exchange methods. A variety of more specialized techniques are available, such as destruction by radiation, dialysis, etc., but are less commonly used.

Table A-10-1
Maximum Permissible Concentrations of Toxic Gases and Vapors in Chemical Finishing Processes

Gas or Vapour	Formula	Western Germany and U.S.A.		U.S.S.R.	
		mg/m3(*)	ppm(*)	mg/m3(*)	ppm(*)
Ammonia	NH_3	70	100	20	28.5
Arsenine	AsH_3	0.2	0.05	0.3	0.075
Benzene	C_6H_6	80	25	100	32
Hydrogen cyanide	HCN	11	10	0.3	0.3
Chlorine	Cl_2	3	1	1	0.3
Formaldehyde	H.CHO	6	5	5	4
Carbon monoxide	CO	110	100	31	26
Methyl alcohol	$CH_3.OH$	260	200	50	39
Perchloroethylene	$CCl_2:CCl_2$	1350	200		
Phosgene	$COCl_2$	0.4	0.1	0.5	0.1
Phosphine	PH_3	Germany → 0.15	0.1	0.3	0.2
		U.S.A. → 0.07	0.05		
Mercury Vapour	Hg	0.1		0.01	
Carbon disulphide	SO_2	13	5	2	0.8
Hydrogen sulphide	CS_2	60	20	10	3.3
Sulphur dioxide	H_2S	30	20	10	7.0
Nitrogen dioxide	NO_2	9	5	5(N_2O_5)	1.0
Carbon tetrachloride	CCl_4	160	25		
Toluene	$C_6H_5.CH_3$	750	200	100	27
Trichloroethylene	$CCl_2:CHCl$	1050	200	50	9
Xylene	 $C_6H_4\begin{smallmatrix}CH_3\\CH_3\end{smallmatrix}$	870	200	100	23
Sulphuric acid fumes	H_2SO_4	1			
Hydrogen selenide	H_2Se	0.2	0.05		
Fluorine	F	0.2	0.1		
Lead dust	Pb	0.15			
Cadmium oxide	CdO	0.1			
Sodium hydroxide fog	NaOH	2			
Sodium or potassium	NaCN				
Cyanide dust	KCN				
Chromic acid or alkali chromate fog	$Na_2Cr_2O_7$	0.1 (CrO_3)			

The following values have been added to supplement Table A-10-1 as they are of special interest in chemical conversion treatments.

Gas or Vapour	Formula	Maximum permissible concentration (mg/m3)*
Ethyl alcohol	$C_2H_5.OH$	1880
Ethylene chloride (dichloroethane)	$CH_2Cl.CH_2Cl$	400
Butyl alcohol	$C_4H_9.OH$	300
Chlorine dioxide	ClO_2	0.3
Carbon dioxide	CO_2	9000
Methylene chloride	CH_2Cl_2	1750
Trichloroethane	$CH_3.CCl_3$	2740
Vinyl chloride	$CH_2=CH.Cl$	1300

* In air at 20°C and 760 mm Hg pressure. ppm = cc gas vapour per cubic metre air.

(1) Chemical Methods

In general, rinse water is first treated to remove cyanide. This is followed by treatment to remove hexavalent chromium. Later, following neutralization, grease and other metals may be removed by precipitation.

1. Cyanide Rinse Chemical Treatment

Chemical methods for treating cyanide rinses include:

- Complete reduction of cyanide by chlorine gas and/or hypochlorites
- Reduction of cyanide to a relatively innocuous cyanite by chlorine and/or hypochlorites
- Conversion of cyanide to ferrus ferrocyanide by treatment with ferrous sulfates.

These methods involve the addition of oxidizing or other reagents to either large tanks with constant agitation (Batch method), or directly to the rinse stream (continuous flow method). Since considerable time is required to fill one tank and treat the cyanide rinse, two tanks are usually employed. This way, one tank can be filling while the treatment process takes place in the other.

In the "destruction of cyanide by chlorine gas" method, chlorine gas must be added under highly alkaline conditions in order to prevent the liberation of HCN which is highly toxic. Since alkaline conditions prevail, the process is accompanied by metallic hydroxides along with carbonates and sulfates (depending on the particular reagents used). If hypochlorites are used, only a suitable salt (in dry or aqueous form) is added to the rinse water, thus minimizing sludge formation. This method is more applicable to smaller plating shops since it requires less expensive equipment.

In the "cyanide immersion" method, cyanide is converted to cyanate which is one thousand times less toxic than cyanide (Reference 6). Conversion processes require only minutes for complete reaction and may be carried out, by the addition of chlorine gas under alkaline conditions or hypochlorites, through either the Batch method or the continuous flow method. Again, it should be mentioned that where chlorine gas is used, sludge formation results.

Cyanides may be precipated as less toxic ferricyanides or ferrocyanides by the synthesis of free cyanide ions with ferric ions. Unfortunately, this method results in large volumes of sludge which must be dealt with. This method is further complicated by the photochemical regeneration of free cyanide in the presence of light.

2. Chromium Rinse Chemical Treatment

Chemical methods for treating chromium rinses include the reduction of hexavalent chromium to a less toxic trivalent chromium using sulfur dioxide of sulfites. Both large and intermediate plating plants reduce hexavalent chromium by using sulfites. The reduction of hexavalent chromium by use of sulfur dioxide gases is also utilized in the larger plants.

Recently, sulfur dioxide has been obtained from waste flue gases in boiler plants. Scrubbers are used for absorption of sulfur dioxide in the chromium waste solutions. Depending upon the concentration of sulfur dioxide available, incomplete reduction may result which would necessitate the use of additional reducing agents.

Reduction,which utilizes agents such as bisulfates, also requires the use of acids in order to maintain acidic conditions (pH 2 to 3). It is possible that some savings may result if sufficient quantities of pickle liquor wastes are available.

In general, chromium reduction techniques produce acidic effluent. This effluent contains reduced chromium and other metals, and requires neutralization. Since cyanide treatments result in alkaline effluents, neutralization of chromium rinse effluents may be achieved by combining the effluents. Generally, neutralization results in the formation of insoluble carbonates and/or hydroxides of chromium, nickel, copper and other plating metals. When ferrous sulfite is used for reduction, iron hydroxide results. Then solid wastes may be removed by sedimentation, evaporation, filtration, etc. Economic recovery of precipitated metals, known as the "waste plus waste method," has been reported by the U.S. Bureau of Mines (Reference 7). Alkaline effluents are combined with stripping solutions to precipitate dissolved metals.

Hexavalent chromium may be precipitated as insoluable barium chromate. However, barium is quite toxic and separation of the precipitate is necessary before disposal.

(2) Evaporative and Ion Exchange Methods

Evaporative and ion exchange methods provide the means for recovery of cyanides, chromic acid, and other plating metals. However, these are practical only when the volume of chromic acid and/or cyanide salts is large enough to be economically advantageous. Plating operations are generally split into several kinds of small chromating and cyanide baths, and recovery becomes impractical. These techniques are perhaps best applied to the treatment of rinse waters following plating operations, so that little or no contamination other than recoverable metal is present.

In ion exchange methods, rinse water is passed through beds of cationic and anionic exchange resins selected for the particular application. The beds must be periodically regenerated to remove the load of cyanides or metals and this requires the use of sulfuric acid and/or sodium hydroxide. These solutions are quite concentrated and generally toxic, and must be treated by disposal methods previously described, if recovery is not feasible.

Ion exchange has been applied to mixed cyanide and chromic wastes effluent using a dual-bed process. Mixed wastes first pass over a cation exchange resin which absorbs metals and helps break up cyanide complexes, then over anionic exchange resins to absorb liberated cyanide.

Both alkali cyanide and acidic metallic solutions may be recovered by evaporative techniques. Rinse waters, contaminated by the plating solution, are evaporated to concentrate the dissolved material and simultaneously produce distilled water.

(3) Electrolytical Methods

Batch wire electrolysis of diluted plating waste has proven to be cost-prohibitive, since reduction of hexavalent chromium and oxidation of cyanide is a slow process in diluted solutions. However, new technology has been designed (Reference 8) to speed up the processes, making them efficient and competitive. Such techniques, however, are not in wide use.

5. IMPACT OF WASTES ON WATER QUALITY

The following paragraphs (Reference 1) summarize the impact of metal plating wastes on the sewage systems, and the water into which sewage effluents are released.

Wastewaters from plating and metal finishing plants always end up in some natural body of water; most of these are surface bodies, but some are possibly subterranean. However, the routes to these natural bodies of water are different. A large majority of establishments run their wastes into municipal sanitary sewers. Once in the sewage system, the industrial wastes are diluted with domestic wastes, carried along with them to a sewage treatment plant, and then to some natural body of water. In the sewage system, the toxicity of the plating waste is decreased by such mechanisms as dilution, mixing, neutralization, and precipitation, with dilution exerting the greatest effect.

There are many finishing establishments situated in areas where there is no municipal sewage system. The wastes from these plants must take a more direct route to natural water bodies. The plants must provide their own treatment before disposal; the extent of this treatment will depend on the composition of the waste and on the levels of pollutants permissible in the stream or lake.

(1) Disposal of Waste into Municipal Sewage Systems

If sufficiently diluted and nearly neutral, plating wastes are only mildly—if at all—corrosive to sewer structures. But serious structural damage from corrosion has occurred from concentrated and acidic wastes not adequately diluted or neutralized before disposal (Reference 9).

Plating wastes can create toxic conditions directly in sewers. Sewer workers have been poisoned by cyanide gases generated from relatively small accumulations of concentrated plating wastes in sewer systems. Even relatively dilute cyanide solutions in sewers can be dangerous. Experimentation has shown that a solution containing as little as 50 ppm of cyanide can generate lethal concentrations of cyanogen in sewer atmospheres. A maximum of 20 ppm of cyanide in sewer water is considered a safe level by some, but other investigators state that 20 ppm of cyanide in small sewers is dangerous and that as low as 10 ppm can be harmful in large sewers where men may work for long hours (Reference 10).

Plating wastes may also exert indirect toxic effects in sewers by promoting the anaerobic decomposition of domestic sewage in sewer lines. Anaerobic decomposition gives rise to the formation of methane (sewer gas) which has been known to suffocate sewer workers and which may cause fires or explosions. Fortunately, there are few instances of these phenomena.

Plating wastes also can cause the blockage of sewers by solids, although this occurs rarely when wastes are sufficiently dilute.

Plating wastes from plants using secondary treatment cause the most damage. This is because the chemicals and metals occurring in these wastes may, if sufficiently concentrated, be toxic to the bacterial colonies which make the process operate. There have been numerous instances where the efficiency of secondary treatment plants has been grossly or completely impaired by slugs of concentrated wastes.

There is another unit operation, practiced by both the primary and secondary types of plants, in which the metals in plating wastes are harmful. This is in the so-called "sludge digestion" step in which primary sludge, either alone or mixed with secondary sludge, is subjected to treatment by anaerobic bacteria. In this process the concentrated sludge, still offensive and toxic, is converted to an innocuous, readily disposable material. Digestion is carried out in the absence of air in large, closed, heated tanks. The digestion process produces a mixture of methane, hydrogen, and carbon dioxide which frequently is burned to supply heat for the sewage plant.

The metal components of the plating wastes concentrate in the settled sludge from primary and secondary treatment and become even more concentrated in the sludge digestion tanks. Instances have been reported where sludge digestion processes were completely halted due to the accumulation of metals (such as copper) in the digestion tanks. It has been estimated that when the total concentration of chromium, copper, nickel, zinc, and cadmium exceeds 400 ppm in digesters, failure can occur. Such concentrations could be produced by raw sewage containing 1.5 to 3 ppm of these metals.

Cyanide does not concentrate in sludges and, in fact, largely decomposes in secondary treatment. However, if the cyanide content of the raw sewage exceeds certain levels, enough may be transferred to the digesters to cause trouble. A steady feed of raw sewage containing 5 ppm of cyanide is capable of disrupting digester operation.

(2) Disposal of Waste into Streams, Lakes, Etc.

One of the benefits of plating wastes disposal via municipal sewers is that the wastes become highly diluted and mixed with other wastes; the toxic components are then removed in the sewage treatment process. This is not true for plants that dispose of their wastes directly into natural streams and lakes. Restrictions on the effluents from these plants are significantly tighter than on effluents destined for municipal sewage systems.

There always is some danger that the components of plating wastes in streams can be harmful to man. Cases have been reported where plating wastes were fed to a stream and caused fatalities to livestock. The major and most frequent danger, however, is the destruction of aquatic life. This can occur with extremely low concentrations of cyanides and metal salts.

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APPENDIX A-11

SIC 80—MEDICAL AND OTHER HEALTH SERVICES

SIC 806—HOSPITALS

1. ECONOMIC STATISTICS

The first hospitals in the United States were established more than 200 years ago. First attempts at caring for the sick was to provide shelter, such as almshouses for the poor. The first of these almshouses was founded in Philadelphia in 1713, followed by others in other areas. The first bona-fide hospital in the United States solely for the physically and mentally ill was established in 1751 and was known as the Pennsylvania Hospital. Other hospitals grew out of a need to provide a place for clinical practice for medical schools. The first listing of hospitals in 1873 showed a total of 178 institutions. By 1909, this count had increased to 4,359 facilities of all types. In 1914, the number rose to 5,047, and increased to 6,852 institutions in 1928, but showed a decline to 6,166 institutions by 1938. However, during this period the total bed capacity increased. In 1963 the number of hospitals increased to almost 8,200.

(1) SIC Classification and Description

SIC 80—Medical and Other Health Services, includes establishments primarily engaged in providing medical or other health services to persons. Associations or groups primarily engaged in providing medical or other health services to members are included, but those which limit services to the provision of insurance against hospitalization or medical costs are excluded.

SIC 806—Hospitals, includes establishments primarily engaged in providing hospital facilities and clinics and dispensaries. Hospitals are divided into two types: (1) general or short-term, and (2) specialty or long-term facilities. These are briefly described as follows:

- General Hospitals — General medical and surgical hospitals are establishments that provide diagnostic and treatment services for patients who have a variety of medical conditions both surgical and non-surgical.

- Specialty Hospitals— These are establishments that usually limit their admissions to patients with specified illnesses or conditions only. These generally include: psychiatric, geriatric and chronic, and tubercular hospitals.

Each state requires that hospitals be licensed in order to operate. However, requirements and standards for licensure vary considerably from state to state. State agencies—in most states, the health department—have the responsibility for the licensing of these facilities. Accreditation standards, unlike licensure, do not vary from state to state. Participation in this program is voluntary on the part of each hospital. Accrediation is made by the Joint Commission on Accreditation of Hospitals (JCAH) for one- or two-year periods or may be withheld if the hospital does not meet specific standards.

(2) Number of Establishments and Relative Concentration

In 1970,there were approximately 6,574 general hospitals, and 1,064 specialty hospitals in the United States (see Table A-11-1). This amounts to a 2 percent decrease in the number of general hospitals, with the southern region having the largest concentration. Among the states reporting the greatest number of general hospitals was California having 582, followed by Texas with 547. The western region had fewer specialty hospitals than other parts of the country. Tubercular hospitals were mostly located in the north central region,with New York leading, followed by California.

Table A-11-1
Hospitals by Region—1970

Region and Division	Total Hospitals	General Medical and Surgical	Specialty				
			Total	Psychiatric	Geriatric and Chronic	Tubercular	Other
United States	7,638	6,574	1,064	494	126	108	336
Regions:							
Northeast.	1,367	1,051	316	148	63	14	91
North Central.	2,181	1,894	287	157	19	46	65
South.	2,649	2,353	296	116	24	38	118
West	1,441	1,276	165	73	20	10	62

(3) Bed Capacity

Table A-11-2 gives a breakdown of both types of hospitals with respect to size in terms of bed capacity. Hospital bed capacity data reveal that the United States had a bed capacity of over 1 million in 1970, approximately 2 percent over that of 1969, or about 5 beds per 1,000 population. The North Central region had the highest bed-to-population ratio. The ratios ranged from 7.6 in North Dakota to 3.9 in Maryland. The specialty hospitals had a capacity of over 500 thousand, about 35 percent of total hospital bed capacity. These were utilized by the psychiatric hospitals (83 percent), geriatric and chronic disease hospitals (7 percent), with tubercular and other hospital services using the remaining 10 percent. The bed-to-population ratio varied from 5.2 (in Massachusetts), to a low of 0.6 beds (in Arkansas). Table A-11-3 shows the number of hospitals, total hospital beds, and bed-to-population ratio for selected years between 1963 and 1970.

(4) Hospital Admissions

During 1970, the general hospitals received about 32 million admissions or about 157 per 1000 population. The southern

Table A-11-2
Bed Size of Hospitals: 1970

Bed size	Total hospitals	General medical and surgical	Specialty				
			Total	Psychi-tric	Geriatric and chronic	Tubercular	Other
Total	7,638	6,574	1,064	494	126	108	336
Less than 25 beds . .	618	508	110	16	6	2	86
25-49	1,658	1,520	138	45	10	9	74
50-74	1,054	944	110	35	15	14	46
75-99	758	661	97	38	10	14	35
100-199	1,554	1,360	194	74	27	31	62
200-299	726	644	82	33	20	13	16
300-499	695	621	74	33	15	20	6
500-999	346	260	86	57	18	5	6
1,000 beds or more .	229	5	173	163	5	-	5

Table A-11-3
Hospitals and Hospital Beds: Selected Years 1963 Through 1970

Year	Total Hospitals	General Medical and Surgical	Specialty				
			Total	Psychiatric	Geriatric and Chronic	Tubercular	Other
	Facilities						
1970.	7,638	4,415	1,064	494	126	108	336
1969.	7,845	6,715	1,130	506	189	116	319
1968.	7,991	6,539	1,452	494	291	129	538
1967.	8,147	6,685	1,462	573	333	169	387
1963.	8,183	6,710	1,473	581	211	258	423
	Beds						
1970.	1,534,779	1,004,415	530,364	437,969	38,144	19,836	34,415
1969.	1,656,908	989,733	576,175	477,309	40,799	20,960	37,116
1968.	1,564,444	934,297	630,147	503,042	43,291	25,381	57,803
1967.	1,631,101	958,729	672,372	545,913	61,211	33,335	31,913
1963.	1,549,952	811,876	738,076	614,014	38,213	50,074	35,658
	Beds per 1,000 Population						
1970.	7.6	5.0	2.6	2.2	0.2	0.1	0.2
1969.	7.8	5.0	2.9	2.4	0.2	0.1	0.2
1968.	7.9	4.7	3.2	2.5	0.2	0.1	0.3
1967.	8.3	4.9	3.4	2.8	0.3	0.2	0.2
1963.	8.3	4.3	4.0	3.3	0.2	0.3	0.2

region accounted for approximately 33 percent of the total, with California and New York showing 17 percent. Discharges just about equalled the admissions. The daily average for patients in the general hospitals,during 1970,numbered 777,442 patients. The total admission and discharge for the general hospitals are given in Table A-11-4.

The specialty hospitals admitted approximately 1.1 million persons during 1970, and discharged about the same number. The northeast region led the nation in number of admissions. Total admissions approximated a ratio of 2.2 average daily residents per 1000 population, and averaged about 450,000 persons per day. These figures are shown in Table A-11-4.

(5) Services

The services provided in the hospitals are varied. The specialty hospital services, in contrast to those of the general hospitals, primarily include department of occupational therapy and social work. Very few of the specialty hospitals reported having surgical departments. However, 9 percent of these hospitals reported having a family planning service. Table A-11-5 shows a detailed breakdown of services for both types of hospitals.

Table A-11-4
Average Daily Patients, Total Admissions, and Discharges for Hospitals by Region - 1970

	Region and Division	Number			Number per 1,000 Population		
		Average Daily Patients	Admissions	Discharges	Average Daily Patients	Admissions	Discharges
General Hospitals	United States	777,442	31,632,665	31,634,594	3.9	156.9	156.9
	Regions:						
	Northeast	195,303	6,848,552	6,854,174	4.0	140.4	140.5
	North Central	228,121	9,097,216	9,092,324	4.0	161.4	161.3
	South	237,121	10,249,186	10,243,504	3.8	166.1	166.0
	West	116,897	5,437,711	5,444,592	3.4	159.3	159.5
Specialty Hospitals	United States	450,557	1,161,726	1,174,534	2.2	5.8	5.8
	Regions:						
	Northeast	171,108	389,773	392,355	3.5	8.0	8.0
	North Central	109,107	257,361	261,999	1.9	4.6	4.6
	South	129,404	343,982	343,987	2.1	5.6	5.6
	West	40,938	170,610	176,193	1.2	5.0	5.2

Table A-11-5
Hospital Services by Type - 1970

Hospital Services	Hospitals Reporting	General Medical and Surgical	Specialty				
			Total	Psychi-atric	Geriatric and Chronic	Tubercular	Other
Total (1)	6,993	6,053	940	460	100	93	287
Blood bank	3,783	3,655	128	65	14	11	38
Cobalt therapy	727	712	15	1	1	-	13
Electroencephalography	2,302	1,978	324	278	5	1	40
Extended care unit	974	732	242	139	53	12	38
Family planning service	641	557	84	63	1	2	18
Histopathology lab.	3,066	2,878	188	109	18	18	43
Home care program	593	476	117	93	3	4	17
Hospital auxiliary	4,636	4,227	409	208	54	21	126
Inhalation therapy dept.	3,523	3,378	145	36	32	33	44
Inten. card. care unit	2,529	2,509	20	10	3	2	5
Intensive care unit	3,068	2,919	149	84	18	16	31
Occupational therapy department	1,600	940	660	405	77	52	126
Open-heart surg. facils.	442	436	6	1	1	-	4
Organ bank	192	174	18	1	-	-	17
Organized outpatient dept.	2,721	2,264	457	162	34	75	186
Pharmacy:							
Full-time registered pharmacist	3,862	3,431	431	274	48	31	78
Part-time registered pharmacist	1,882	1,631	251	98	40	40	73

(1) Excludes 645 hospitals not reporting

Table A-11-5
(Continued)

Hospital Services	Hospitals Reporting	General Medical and Surgical	Specialty				
			Total	Psychiatric	Geriatric and Chronic	Tubercular	Other
Physical therapy dept.	4,176	3,743	433	184	83	19	147
Postoperative rec. rm.	4,770	4,507	263	106	14	36	107
Premature nursery	2,471	2,450	21	1	-	-	20
Psychiatric services:							
Inpatient unit	1,419	947	472	432	16	4	20
Outpatient unit	1,175	834	341	316	5	-	20
Partial hosp. prog.	739	450	289	272	3	1	13
Emergency services	1,142	913	229	224	1	-	4
Psychiatric foster and/or home care	242	70	172	169	1	-	2
Radioisotope facility	2,175	2,132	43	12	3	1	27
Radium therapy	1,583	1,562	21	5	2	-	14
Rehabilitation services:							
Inpatient unit	994	622	372	181	54	24	113
Outpatient unit	793	594	199	88	18	4	89
Renal analysis:							
Inpatient unit	649	642	7	1	1	-	5
Outpatient unit	430	424	6	1	1	-	4
Self-care unit	541	397	144	89	16	7	32
Social work department	2,379	1,678	701	412	67	69	153
X-ray therapy	1,997	1,947	50	22	6	1	21

Source: Unpublished data from the National Center for Health Statistics master facility census.

(6) Hospital Employment

In 1970, nearly 2.5 million persons were employed either full- or part-time in the general hospitals. Approximately 80 percent of these were full-time employees, averaging out to 2.9 full-time employees per patient. In the specialty hospitals, more than 400,000 persons were employed, of which 379,000 or about 95 percent were full-time personnel. There was less than one full-time employee per patient. Seventeen states reported more than one full-time employee per patient.

2. WASTE CHARACTERISTICS

(1) Description of Hospital Wastes

Waste materials generated by hospitals can be divided into several descriptive types which include the following:

- General rubbish—Composed of housekeeping materials such as newspapers, cardboard and other paperstuff, flowers, scraps from wastebaskets, disposable gowns, linens, splints, rubber and cloth.
- Food residues—Self explanatory.

- Pathological wastes—Comprised of tissue taken at autopsy or during surgical procedures, animal carcasses and wastes, microbiological wastes and cultures, bandaging material, blood and serum.
- Radioactive wastes—Self explanatory.
- Drug residues and solvents—Includes glass and plastic containers.
- Syringes, needles test tubes and other disposable surgical items—Self explanatory.

An increasing volume of solid waste generated by hospitals is due,in large part,to the use of disposable or use-and-discard items in the hospital environment. As a minimum, approximately 125 such articles are in constant use in the performance of surgical techniques, laboratory functions, diet preparations, nursing and general housekeeping services. Two reasons why plastic and/or other types of disposable items have enjoyed ever-increasing use are:(1) the role they play in controlling infection, and (2) economy. In spite of well-designed systems for autoclaving and maintaining sterility, a greater potential for infection exists with reusable items than with the use of disposable counterparts.

The economy factor associated with the use of disposables is not as well documented. Although economies are present in certain areas, additional expense and demands are present in others. The increase in bulky shipping cartons alone, adds considerably to the solid waste volume. Increases in other elements of hospital waste appear to be related directly to the patient load of the hospitals.

(2) Hazardous Materials in Hospital Wastes

Accident risk involved in the disposal of needles, syringes, glass and surgical items, as well as personal and/or environmental contamination associated with the handling and disposal of pathological materials, appear to be the unique problems associated with disposal of hospital wastes. The quantities of drug residues, radioactive wastes or other special chemical wastes do not appear to present signal hazards. Although radiopharmaceuticals are being used in increasing quantity, the half-life of the diagnostic agents used is quite short and thus, unused materials and other radioactive wastes decay very quickly to low radiation levels.

The amount of hospital waste has increased from approximately 4 pounds/patient/day, in 1955, to a current figure of approximately 19 pounds/patient/day. The estimated per capita figure for the

United States population is approximately five pounds per day. One reason for the larger figure estimated for the hospital patient,is that there are 2.9 full-time hospital employees per patient, each contributing substantially to the solid wasteload of the hospital.

3. CURRENT DISPOSAL PRACTICES

The majority of hospitals dispose of solid waste by incineration, landfill or a combination of the two processes. Prior to removal to landfill, many institutions utilize compacting to reduce the volume of waste that must be disposed of. Liquid wastes are diluted or neutralized and introduced into the sewage system. Pathological wastes are usually incinerated. However, prior to incineration, microbiological wastes may be autoclaved. Radioactive wastes are given to service contracters or returned to the manufacturer. Unused drug products are flushed into the sewage system, incinerated or returned to the manufacturer. Syringes and needles are broken or crushed prior to incineration or removal to landfill. Several hospitals sterilize food residues and make them available for animal feed.

To obtain some estimate of waste material quantities and composition, inquiries were made at a number of general hospitals representing a total of 5,281 beds. At each institution, the hospital administrator or his designate provided available information. A summary of waste quantities estimated for each of the hospitals is presented in the following tabulation:

Hospital	Number of Beds	Estimated Solid Waste (pounds/day)
1	1300	32,000
2	1000	7,200
3	758	7,000
4	600	3,500
5	430	19,000
6	377	3,000
7	350	2,800
8	350	7,650
9	116	2,700
Total	5,281	85,200

The estimated average wasteload for these hospitals, as a group, is 16.13 pounds/bed/day and the range 5.8 - 45.0 pounds/bed/day.

Disposal practices employed by some of these hospitals are as follows:

Hospital No. 1 - The facility disposes of approximately 32,000 pounds of waste per day using incineration, compacting and sanitary landfill. Approximately 16,000 pounds are incinerated. Pathologic wastes and all microbiological materials are included in that fraction that is incinerated. Radioactive wastes are disposed of by service contract. Unused drugs are returned to the manufacturer or flushed into the municipal sewage system.

Hospital No. 2 - The waste is divided into several types: (1) solid wastes including papers, flowers, general trash; (2) food residues; (3) non-burnables such as plastic and rubber materials; (4) pathological wastes, including animal carcasses, autopsy and surgical wastes and microbiological wastes (tubes, cultures, petri dishes); (5) radioactive wastes; (6) syringes and needles; and (7) return or low potency drugs.

Solid wastes (7,000 pounds) are incinerated daily at a municipal incinerator. Food residues (100 pounds per day) are sold to a farmer who, in turn, sterilizes the material and utilizes it as animal fodder. Non-burnables (100 pounds/day) are disposed of at a municipal dump. Hypodermic needles and syringes, included as burnables, are disassembled and broken prior to incineration. Pathological wastes are incinerated before or after autoclaving. Liquid residues are autoclaved, diluted and poured into the drain. Radioactive wastes are disposed of by service contract except for syringes. These are stored in a lead vehicle until a low-level of radioactivity is reached at which time they are disposed of by incineration.

Hospital No. 7 - Solid wastes (3,000 pounds/day) are disposed of primarily by a contract service. No information as to the final disposition (incineration, landfill) was available. Autopsy remains are either incinerated or buried on the premises. Microbiological wastes are autoclaved prior to incorporation into the general waste collection.

The disposal practices described for these hospitals are typical of those employed by all the hospitals at which inquiries were made. The following conclusions were derived from the information obtained:

- The quantity of solid wastes generated by hospitals is increasing annually.
- The rate of increase in solid waste generation is largely the result of the broad usage of "use and discard items" in the medical and surgical environment.
- The primary methods of solid waste disposal practiced by hospitals are incineration and landfill, or a combination

of the two. Pretreatment consists of compacting and in some instances, sterilization.

- Although estimates of total solid wastes are available, quantitative data for pathological and other potentially hazardous wastes are limited and unreliable.

Although some information regarding the quantity and composition of solid hospital waste was obtained from several hospitals, minimal information describing the quantities of pathological wastes generated was obtained. One estimate was obtained from a survey of solid waste practices utilized by the United States Air Force (Reference 1). A questionnaire survey of solid waste practices was conducted on all Air Force installations and data were made available on 98 major installations. To obtain an idea of the composition of the pathological wastes generated, the questionnaire requested percentages in the following categories: tissues, plastics, bandages, paper and "other." Some items described in the response to the "other" category included: syringes, kitchen wastes, serum, cardboard, drugs, glass, blood, splints, vials, test tubes, petri dishes, cultures, needles, metal, rubber and cloth. The difficulty in obtaining accurate quantitative composition data is obvious.

Reported pathological waste generated at medical treatment facilities varied from 0 to 22,700 pounds per week. For 77 bases with an in-patient capability, the per capita production of pathological wastes varied from 0.04 pounds per bed per week to 181.6 pounds per bed per week. There were 21 bases having no beds or no estimate of the amount of pathological waste. The mean for those installations having in-patient capability (77) was determined to be 5.63 pounds per bed per week (median = 1.21 pounds per bed per week). The majority of the installations dispose of these wastes by incineration and landfill. Of the bases reporting, 68.0 percent use incineration only, 13.4 percent use landfill only, 16.5 percent use a combination incineration and landfill, and the remaining 2.1 percent utilize incineration, landfill and sewage disposal. Approximately 40 percent of those installations using landfill as the primary disposal technique autoclave the materials prior to disposal.

4. HAZARDOUS EFFECTS OF WASTES

The danger of disease transmission from hospital wastes is present to a greater degree than from ordinary domestic refuse. The cart system of collection, used within the hospital facility, results in a potential for contamination and accident. Several hospitals use gravity chutes for collecting waste from the generation source,prior to removal to disposal sites. Microbiological studies performed on these installations have suggested a contribution to environmental contamination.

There does not appear to be any clearly defined solution to the potential problem of environmental contamination resulting from hospital wastes. A wet pulping system is receiving some use as a desirable means of waste collection. The system reduces the majority of wastes to a pulp or slurry which is dewatered prior to transport to the ultimate disposal site. Although the weight of residues is considerably greater than that of the original material,because of the water residue, an 85 percent reduction in volume is accomplished.

To minimize the accident and contamination risk accompanying the increased use of disposable items (syringes, needles, blades, etc.), hospitals are currently destroying such items prior to incineration, disposal or landfill sites. Another approach currently under investigation is a low-temperature melting process by which such items can be cast into blocks for ultimate disposal. This process would entrap infective material within the mass and also permit sterilization of the exposed surface area.

The possibility of environmental contamination by incinerator effluents also exists. Although air pollution control regulations usually require a minimum of effluent contaminants, the control devices (settling chambers, scrubbers), are not designed to control the emissions of pathogenic organisms which require high temperature destruction.

Hazards associated with the disposal of radioactive wastes, although possible, do not appear to be of great magnitude. The majority of materials used routinely have relatively short half-lives and decay to safe levels of emitted radiation is rapid. Chemical toxicity associated with these substances is small because of the relatively low concentration of chemical entities in radioactive pharmaceuticals.

REFERENCES

1. Solid Waste Practices in the United States Air Force, U.S. Air Force, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, Technical Report No. AFWL-TR-71-119, October 1971.

APPENDIX A-12

RADIOACTIVE WASTE

ATOMIC ENERGY COMMISSION

1. INTRODUCTION

The radioactive waste materials produced in the United States are from operations of the U.S. Atomic Energy Commission (AEC), from a rapidly growing nuclear power industry, and from medical and industrial applications. Most of the presently stored and buried radioactive wastes are from past AEC operations having to do with our nuclear weapons program. The AEC accumulated wastes are discussed in Section 5 of this Appendix. In the future, our largest quantities of radioactive wastes will result from the operations of nuclear reactors in the power industry and the associated nuclear fuel cycle. In practice medical and industrial applications do not produce significant quantities of radiotoxic waste materials. This also holds true for many of the steps in the nuclear fuel cycle. Mining, milling, conversion and enrichment operations produce some radioactive wastes since uranium is in itself radioactive. The wastes from these operations, however, are small, both quantity-wise and toxicity-wise, compared to those produced by the fissioning of uranium within the fuel assemblies of a nuclear power reactor. When the reactor fuel assemblies are spent they are transferred to a reprocessing plant for recovery of the unused uranium and the produced plutonium, and it is during this operation that high-level waste is collected. The fuel fabrication operations which utilize recovered plutonium are also significant producers of radiotoxic wastes.

2. HAZARDOUS EFFECTS RATING

It is essential to remember during a reading of the following sections of this appendix that the quantities of radioactive matter released during the various operations are given in curies (1) but that the potential hazard is not directly in proportion to the curies released. The measure of the hazard is the potential radiation dose which may be received by humans from the release of given curie quantities of specific radionuclides. The radiation dose unit is rem (2).

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(1) A curie (Ci) is a unit denoting an activity of 3.7 x 10^{10} disintegration per second from a given quantity of radioactive material.

(2) A rem is a unit of dose equivalent to an imparted energy of 100 ergs/gram of matter times quality and distribution factors.

In this respect the International Committee on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) have established limits of exposure for the general public and have classified the radioisotopes on the basis of the concentrations that are permissible as soluble or insoluble material in air and in water media without exceeding the exposure limits. To illustrate, an examination of the two radionuclides Na-22 and Tc-99m in an insoluble form would show that a microcurie (μCi or 10^{-6}Ci) of each would expose the lung of a man to 0.8 rem and 0.00053 rem, respectively. That is, Na-22 in this form would produce a dose 1500 times greater than an equal quantity of Tc-99m. Accordingly, to assure an equal degree of safety, the maximum permissible concentrations (MPC) of these radionuclides allowed in the air for their insoluble forms are 3×10^{-10} μc/ml and 5×10^{-7} μCi/ml, respectively, or roughly in the inverse ratio to the radiation exposure dose that equal quantities of each would produce.

In addition to determining MPC's for the radionuclides based on the exposure they produce per unit quantity of intake, other effects, such as an ability of a plant or an animal to concentrate a particular isotope, are taken into consideration when determining its acceptable concentration. In some cases it is necessary to restrict the total quantity release of a particular isotope rather than permit the release of unlimited quantities at low concentration. In Table A-12-1 a tabulation based on the relative hazard rating of the radionuclides is given. This specific rating system was developed in connection with the establishment of the agreed upon international quantity limitations that have been placed on packages (Type A and Type B). In addition to quantity limitations each of these types of packages must meet specific performance requirements before it is an acceptable package for use in transporting radioactive materials.

In its regulatory program the U.S. Atomic Energy Commission has announced a policy of restricting radioactive releases to the environment to "as low as practicable" and have generally defined this value for light water power reactors.

At the recent rulemaking hearings of the U.S. AEC the design objectives were set forth with regard to effluents from light water reactors. In the case of liquid effluents, the design objectives were established such that, under the unlikely conditions whereby an individual received his total drinking water supply and a portion of his food from the effluent discharge, the exposure would not exceed 5 mrem/year. Briefly, the exposure was limited to this value by establishing as the design objectives 20 pCi/1 (2 x 10^{-11}Ci/1)

Table A-12-1

Radioisotopes Listed in Order of Relative Hazard

Nuclide (1)	(2)	Insoluble form: Lung Dose (rem/μc) (3)	Insoluble form: (MPC) a 168 hr wk μc/ml (4)	Soluble form: (MPC) a 168 hr wk μc/ml (5)	Soluble form: Inhalation dose (rem/μc) (6)	Soluble form: Critical organ (7)	Soluble form: Wound dose (rem/μc) (8)	Maximum permissible body burden (μc) (9)	Specific activity c/g (10)
$_{90}Th^{230}$	Thorium-230	5.4 × 10	3×10^{-12}	8×10^{-13}	2.8×10^{4}	Bone	*1.1×10^{5}	0.05	1.94×10^{-2}
$_{91}Pa^{231}$	Protactinium-231	6.1 × 10	4×10^{-11}	4×10^{-13}	9.0×10^{3}	Bone	*3.6×10^{4}	0.02	4.52×10^{-2}
$_{94}Pu^{239}$	Plutonium-239	6.0 × 10	10^{-11}	6×10^{-13}	7.0×10^{3}	Bone	*3.0×10^{4}	0.04	6.1×10^{-2}
$_{94}Pu^{240}$	Plutonium-240	6.0 × 10	10^{-11}	6×10^{-13}	7.0×10^{3}	Bone	*3.0×10^{4}	0.04	2.27×10^{-1}
$_{98}Cf^{249}$	Californium-249	6.8 × 10	3×10^{-11}	5×10^{-13}	7.0×10^{3}	Bone	*2.8×10^{4}	0.04	3.05
$_{94}Pu^{242}$	Plutonium-242	5.8 × 10	10^{-11}	6×10^{-13}	6.0×10^{3}	Bone	*2.4×10^{4}	0.05	3.9×10^{-3}
$_{89}Ac^{227}$	Actinium-227	2.6×10^{2}	9×10^{-12}	8×10^{-13}	5.0×10^{3}	Bone	*2.0×10^{4}	0.03	7.2 × 10
$_{93}Np^{237}$	Neptunium-237	5.6 × 10	4×10^{-11}	10^{-12}	2.8×10^{3}	Bone	*1.2×10^{4}	0.06	6.9×10^{-4}
$_{96}Cm^{245}$	Curium-245	6.2 × 10	4×10^{-11}	2×10^{-12}	2.8×10^{3}	Bone	*1.1×10^{4}	0.04	1.04×10^{-1}
$_{98}Cf^{250}$	Californium-250	6.8 × 10	3×10^{-11}	2×10^{-12}	2.4×10^{3}	Bone	*1.0×10^{4}	0.04	1.31×10^{2}
$_{96}Cm^{246}$	Curium-246	6.3 × 10	4×10^{-11}	2×10^{-12}	2.2×10^{3}	Bone	*9.0×10^{3}	0.05	3.64×10^{-1}
$_{95}Am^{241}$	Americium-241	6.5 × 10	4×10^{-11}	2×10^{-12}	2.2×10^{3}	Bone	*9.0×10^{3}	0.05	3.24
$_{95}Am^{243}$	Americium-243	6.1 × 10	4×10^{-11}	2×10^{-12}	2.0×10^{3}	Bone	*8.0×10^{3}	0.05	1.85×10^{-1}
$_{96}Cm^{243}$	Curium-243	6.7 × 10	3×10^{-11}	2×10^{-12}	1.8×10^{3}	Bone	*7.0×10^{3}	0.09	4.21 × 10
$_{96}Cm^{244}$	Curium-244	6.7 × 10	3×10^{-11}	3×10^{-12}	1.3×10^{3}	Bone	*5.5×10^{3}	0.1	8.2 × 10
$_{90}Th^{228}$	Thorium-228	2.3×10^{2}	2×10^{-12}	3×10^{-12}	1.0×10^{3}	Bone	*4.0×10^{3}	0.02	8.3×10^{2}
$_{94}Pu^{238}$	Plutonium-238	6.4 × 10	10^{-11}	7×10^{-13}	7.0×10^{2}	Bone	*2.8×10^{3}	0.04	1.68 × 10
$_{98}Cf^{252}$	Californium-252	2.1×10^{2}	10^{-11}	2×10^{-12}	5.5×10^{2}	Bone	*2.2×10^{3}	0.01	6.5×10^{2}
$_{88}Ra^{226}$	Radium-226	1.3×10^{2}	6×10^{-8}	10^{-11}	3.0×10^{2}	Bone	*1.0×10^{3}	0.1	9.8×10^{-1}

Table A-12-1 (Continued)

Nuclide		Insoluble form		Soluble form				Maximum permissible body burden (μc)	Specific activity c/g
		Lung Dose (rem/μc)	(MPC)a 168 hr wk μc/ml	(MPC)a 168 hr wk μc/ml	Inhalation dose (rem/μc)	Critical organ	Wound dose (rem/μc)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$_{94}Pu^{241}$	Plutonium-241	5.9×10^{-2}	10^{-8}	3×10^{-11}	1.3×10^{3}	Bone	$*5.5 \times 10^{2}$	0.9	1.14×10^{2}
$_{92}U^{232}$	Uranium-232	2.3×10^{3}	9×10^{-12}	3×10^{-11}	1.1×10^{3}	Bone	$*4.5 \times 10^{3}$	0.01	2.08×10
$_{88}Ra^{228}$	Radium-228	1.7×10^{3}	10^{-11}	2×10^{-11}	1.2×10^{2}	Bone	$*4.0 \times 10^{3}$	0.06	2.34×10^{2}
$_{82}Pb^{210}$	Lead-210	2.8×10	8×10^{-11}	4×10^{-11}	5.5×10	Kidney	$*2.0 \times 10^{3}$	0.4	8.8×10
$_{96}Cm^{242}$	Curium-242	4.3×10	6×10^{-11}	4×10^{-11}	5.0×10	Liver	$*2.0 \times 10^{2}$	0.05	3.32×10^{3}
$_{90}Th^{227}$	Thorium-227	4.0×10	6×10^{-11}	10^{-10}	2.8×10	Bone	$*1.1 \times 10^{3}$	0.02	3.17×10^{4}
$_{92}U^{233}$	Uranium-233	5.5×10	4×10^{-11}	2×10^{-10}	2.3×10	Bone	$*9.0 \times 10$	0.05	9.5×10^{-3}
$_{92}U^{234}$	Uranium-234*	5.4×10	4×10^{-11}	2×10^{-10}	2.3×10	Bone	$*9.0 \times 10$	0.05	6.2×10^{-3}
$_{38}Sr^{90}$	Strontium-90	1.2	2×10^{-9}	10^{-10}	3.6×10	Bone	$*9.0 \times 10$	2.0	1.45×10^{2}
$_{92}U^{236}$	Uranium-236	5.3×10	4×10^{-11}	2×10^{-10}	1.9×10	Bone	$*7.5 \times 10$	0.06	6.3×10^{-5}
$_{97}Bk^{249}$	Berkelium-249	5.6×10^{-2}	4×10^{-8}	3×10^{-10}	1.2×10	Bone	$*5.0 \times 10$	0.7	1.8×10^{3}
$_{84}Po^{210}$	Polonium-210	3.4×10	7×10^{-11}	2×10^{-10}	1.2×10	Spleen	$*5.0 \times 10$	0.03	4.5×10^{3}
$_{92}U^{230}$	Uranium-230	$*6.7 \times 10$	4×10^{-11}	10^{-10}	1.1×10	Bone	4.2×10	7×10^{-3}	2.73×10^{4}
$_{88}Ra^{223}$	Radium-223	$*3.6 \times 10$	8×10^{-11}	6×10^{-10}	5.5	Bone	1.4×10	0.05	5.0×10^{4}
$_{88}Ra^{224}$	Radium-224	$*1.7 \times 10$	2×10^{-10}	2×10^{-9}	1.6	Bone	4.0	0.06	1.6×10^{5}
$_{91}Pa^{230}$	Protactinium-230	3.7×10^{-3}	3×10^{-10}	6×10^{-10}	6.0	Bone	$*2.6 \times 10$	0.07	3.21×10^{4}
$_{89}Ac^{228}$	Actinium-228	$*2.4$	6×10^{-9}	3×10^{-8}	2.0×10^{-1}	Bone	8.0×10^{-1}	0.04	2.24×10^{6}
$_{63}Eu^{154}$	Europium-154	9.6×10^{-1}	2×10^{-9}	10^{-9}	3.3	Bone	$*1.3 \times 10$	5.0	1.45×10^{2}
$_{58}Ce^{144}$	Cerium-144	1.0	2×10^{-9}	3×10^{-9}	1.1	Bone	$*4.5$	5.0	3.18×10^{3}
Th^{nat}	Natural thorium	2.8×10^{2}	10^{-12}	6×10^{-13}	3.6×10^{4}	Bone	1.4×10^{5}	0.01	Special Definition
$_{90}Th^{232}$	Thorium-232	5.2×10	4×10^{-12}	7×10^{-13}	3.6×10^{4}	Bone	$*1.3 \times 10^{5}$	0.04	1.11×10^{-7}
$_{62}Sm^{147}$	Samarium-147	2.6×10	7×10^{-11}	2×10^{-11}	2.0×10^{3}	Bone	$*8.0 \times 10^{3}$	0.1	1.95×10^{-8}
$_{60}Nd^{144}$	Neodymium-144*	2.3×10	10^{-10}	3×10^{-11}	2.0×10^{3}	Bone	$*8.0 \times 10^{3}$	0.1	4.97×10^{-13}
$_{92}U^{238}$	Uranium-238	4.9×10	5×10^{-11}	3×10^{-11}	8.0×10	Kidney	$*3.0 \times 10^{3}$	5×10^{-3}	3.33×10^{-7}
U^{nat}	Natural uranium	1.1×10^{2}	2×10^{-11}	3×10^{-11}	8.0×10	Bone	$*3.0 \times 10^{3}$	0.03	Special Definition
$_{92}U^{235}$	Uranium-235	5.1×10	4×10^{-11}	2×10^{-10}	1.9×10	Bone	$*7.5 \times 10$	0.03	2.14×10^{-6}
$_{53}I^{129}$	Iodine-129	9.3×10^{-2}	2×10^{-8}	6×10^{-10}	7.0	Thyroid	$*9.0$	3.0	1.62×10^{-4}
$_{83}Bi^{210}$	Bismuth-210	2.0	2×10^{-9}	2×10^{-9}	1.1	Kidney	$*4.0$	0.04	6.6×10^{-4}
$_{53}I^{126}$	Iodine-126	2.5×10^{-2}	10^{-7}	3×10^{-9}	1.8	Thyroid	$*2.2$	1.0	7.8×10^{4}
$_{53}I^{131}$	Iodine-131	3.0×10^{-2}	10^{-7}	3×10^{-9}	1.6	Thyroid	$*2.0$	0.7	1.23×10^{5}
$_{85}At^{211}$	Astatine-211	1.1	10^{-8}	2×10^{-9}	1.4	Thyroid	$*1.8$	0.02	2.06×10^{6}
$_{63}Eu^{152}$	Europium-152 (13 yrs)	3.7×10^{-1}	6×10^{-9}	4×10^{-9}	4.5×10^{-1}	Kidney	$*1.8$	20.0	1.85×10^{2}
$_{82}Pb^{212}$	Lead-212	$*1.7$	7×10^{-9}	6×10^{-9}	4.0×10^{-1}	Kidney	1.4	0.02	1.4×10^{6}
$_{69}Tm^{170}$	Thulium-170	2.0×10^{-1}	10^{-8}	10^{-8}	4.0×10^{-1}	Bone	$*1.5$	9.0	6.0×10^{3}
$_{39}Y^{91}$	Yttrium-91	2.3×10^{-1}	10^{-8}	10^{-8}	3.3×10^{-1}	Bone	$*1.3$	5.0	2.50×10^{4}
$_{44}Ru^{106}$	Ruthenium-106	$*1.2$	2×10^{-9}	3×10^{-8}	3.6×10^{-2}	Kidney	1.5×10^{-1}	3.0	3.38×10^{3}
$_{38}Sr^{89}$	Strontium-89	2.0×10^{-1}	10^{-8}	10^{-8}	4.0×10^{-1}	Bone	$*1.0$	4.0	2.88×10^{4}

Table A-12-1 (Continued)

Nuclide		Insoluble form		Soluble form				Maximum permissible body burden (μc)	Specific activity c/g
		Lung Dose (rem/μc)	(MPC) a 168 hr wk μc/ml	(MPC) a 168 hr wk μc/ml	Inhalation dose (rem/μc)	Critical organ	Wound dose (rem/μc)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$_{11}Na^{22}$	Sodium-22	*8.0 × 10⁻¹	3 × 10⁻⁹	6 × 10⁻⁸	1.8 × 10⁻²	Total Body	2.2 × 10⁻²	10	6.3 × 10³
$_{38}Sr^{92}$	Strontium-92	*1.2 × 10⁻²	10⁻⁷	2 × 10⁻⁷	2.4 × 10⁻³	Bone	6.0 × 10⁻³	2	1.26 × 10⁷
$_{27}Co^{60}$	Cobalt-60	*7.7 × 10⁻¹	3 × 10⁻⁹	10⁻⁷	8.0 × 10⁻³	Total Body	2.0 × 10⁻²	10	1.14 × 10³
$_{61}Pm^{147}$	Promethium-147	7.0 × 10⁻²	3 × 10⁻⁸	2 × 10⁻⁸	2.0 × 10⁻¹	Bone	*7.0 × 10⁻¹	60	9.4 × 10²
$_{62}Sm^{151}$	Samarium-151	4.8 × 10⁻²	5 × 10⁻⁸	2 × 10⁻⁸	2.0 × 10⁻¹	Bone	*7.0 × 10⁻¹	100	2.55 × 10
$_{90}Th^{234}$	Thorium-234	1.9 × 10⁻¹	10⁻⁸	2 × 10⁻⁸	1.8 × 10⁻¹	Bone	*7.0 × 10⁻¹	4	2.32 × 10⁴
$_{48}Cd^{115m}$	Cadmium-115m	2.0 × 10⁻¹	10⁻⁸	10⁻⁸	1.8 × 10⁻¹	Liver	*7.0 × 10⁻¹	3	2.64 × 10⁴
$_{73}Ta^{182}$	Tantalum-182	3.2 × 10⁻¹	7 × 10⁻⁹	10⁻⁸	1.8 × 10⁻¹	Liver	*7.0 × 10⁻¹	7	6.2 × 10³
$_{72}Hf^{181}$	Hafnium-181	9.6 × 10⁻²	3 × 10⁻⁸	10⁻⁸	1.6 × 10⁻¹	Spleen	*7.0 × 10⁻¹	4	1.62 × 10⁴
$_{47}Ag^{110m}$	Silver-110m	*7.6 × 10⁻¹	3 × 10⁻⁹	7 × 10⁻⁸	8.0 × 10⁻³	Kidney	3.0 × 10⁻²	10	4.70 × 10³
$_{20}Ca^{45}$	Calcium-45	5.7 × 10⁻²	4 × 10⁻⁸	10⁻⁸	3.6 × 10⁻¹	Bone	*6.0 × 10⁻¹	30	1.91 × 10⁴
$_{55}Cs^{134}$	Caesium-134	*5.6 × 10⁻¹	4 × 10⁻⁹	10⁻⁸	9.0 × 10⁻²	Liver	1.3 × 10⁻¹	20	1.22 × 10³
$_{53}I^{133}$	Iodine-133	1.9 × 10⁻²	7 × 10⁻⁸	10⁻⁸	4.0 × 10⁻¹	Thyroid	*5.5 × 10⁻¹	0.3	1.13 × 10⁶
$_{40}Zr^{93}$	Zirconium-93	2.2 × 10⁻²	10⁻⁷	4 × 10⁻⁸	1.3 × 10⁻¹	Bone	*5.0 × 10⁻¹	100	3.5 × 10⁻³
$_{83}Bi^{207}$	Bismuth-207	*4.9 × 10⁻¹	5 × 10⁻⁹	6 × 10⁻⁸	4.5 × 10⁻²	Kidney	1.6 × 10⁻¹	2	2.16 × 10²
$_{55}Cs^{137}$	Caesium-137	*4.6 × 10⁻¹	5 × 10⁻⁹	2 × 10⁻⁸	8.0 × 10⁻²	Liver	1.1 × 10⁻¹	30	9.82 × 10
$_{63}Eu^{155}$	Europium-155	9.0 × 10⁻²	3 × 10⁻⁸	3 × 10⁻⁸	1.2 × 10⁻¹	Bone	*4.5 × 10⁻¹	70	1.36 × 10³
$_{48}Cd^{109}$	Cadmium-109	9.0 × 10⁻²	3 × 10⁻⁸	2 × 10⁻⁸	1.1 × 10⁻¹	Kidney	*4.5 × 10⁻¹	20	2.53 × 10³
$_{69}Tm^{171}$	Thulium-171	2.9 × 10⁻²	8 × 10⁻⁸	4 × 10⁻⁸	1.1 × 10⁻¹	Bone	*4.5 × 10⁻¹	90	1.12 × 10³
$_{51}Sb^{124}$	Antimony-124	*3.7 × 10⁻¹	7 × 10⁻⁹	5 × 10⁻⁸	2.8 × 10⁻²	Bone	9.0 × 10⁻²	10	1.76 × 10⁴
$_{41}Nb^{93m}$	Niobium-93m	4.2 × 10⁻²	5 × 10⁻⁸	4 × 10⁻⁸	1.0 × 10⁻¹	Bone	*3.6 × 10⁻¹	200	1.05 × 10³
$_{65}Tb^{160}$	Terbium-160	2.1 × 10⁻¹	10⁻⁸	3 × 10⁻⁸	8.0 × 10⁻²	Bone	*3.6 × 10⁻¹	20	1.11 × 10⁴
$_{49}In^{114m}$	Indium-114m	*3.4 × 10⁻¹	7 × 10⁻⁹	4 × 10⁻⁸	6.0 × 10⁻³	Kidney	2.4 × 10⁻²	6	2.29 × 10⁴
$_{21}Sc^{46}$	Scandium-46	*3.1 × 10⁻¹	8 × 10⁻⁹	8 × 10⁻⁸	3.6 × 10⁻²	Liver	1.4 × 10⁻¹	10	3.38 × 10⁴
$_{56}Ba^{140}$	Barium-140	1.9 × 10⁻¹	10⁻⁸	4 × 10⁻⁸	8 × 10⁻²	Bone	*3.0 × 10⁻¹	4	7.3 × 10⁴
$_{17}Cl^{36}$	Chlorine-36	*2.9 × 10⁻¹	8 × 10⁻⁹	10⁻⁷	5.5 × 10⁻³	Total Body	7.0 × 10⁻³	80	3.21 × 10⁻²
$_{77}Ir^{192}$	Iridium-192	*2.7 × 10⁻¹	9 × 10⁻⁹	4 × 10⁻⁸	5.0 × 10⁻³	Kidney	1.5 × 10⁻¹	6	9.1 × 10³
$_{15}P^{32}$	Phosphorus-32	1.0 × 10⁻¹	3 × 10⁻⁸	2 × 10⁻⁸	1.8	Bone	*1.1 × 10⁻¹	6	2.88 × 10⁵
$_{83}Bi^{212}$	Bismuth-212	1.9 × 10⁻¹	7 × 10⁻⁸	3 × 10⁻⁸	7.0 × 10⁻²	Kidney	*2.6 × 10⁻¹	0.01	1.47 × 10⁷
$_{81}Tl^{204}$	Thallium-204	*2.6 × 10⁻¹	9 × 10⁻⁹	2 × 10⁻⁷	1.5 × 10⁻²	Kidney	3.0 × 10⁻²	10	4.28 × 10²
$_{52}Te^{129m}$	Tellurium-129m	*2.6 × 10⁻¹	10⁻⁸	3 × 10⁻⁸	9.0 × 10⁻²	Kidney	2.0 × 10⁻¹	3	2.47 × 10⁴
$_{28}Ni^{63}$	Nickel-63	2.4 × 10⁻²	10⁻⁷	2 × 10⁻⁸	9.0 × 10⁻²	Bone	*2.4 × 10⁻¹	200	45.5
$_{40}Zr^{95}$	Zirconium-95	*2.2 × 10⁻¹	10⁻⁸	4 × 10⁻⁸	5.5 × 10⁻²	Bone	*2.2 × 10⁻¹	20	2.12 × 10⁴
$_{64}Gd^{153}$	Gadolinium-153	7.5 × 10⁻²	3 × 10⁻⁸	8 × 10⁻⁸	5.0 × 10⁻²	Bone	*2.2 × 10⁻¹	90	3.62 × 10³
$_{51}Sb^{125}$	Antimony-125	2.6 × 10⁻¹	9 × 10⁻⁹	2 × 10⁻⁷	1.6 × 10⁻²	Lung (Sol)	6.0 × 10⁻³	40	1.43 × 10³
$_{49}In^{115}$	Indium-115	*1.9 × 10⁻¹	10⁻⁸	9 × 10⁻⁸	2.4 × 10⁻²	Kidney	1.0 × 10⁻¹	30	5.2 × 10⁻¹²
$_{25}Mn^{54}$	Manganese-54	*1.9 × 10⁻¹	10⁻⁸	10⁻⁷	1.4 × 10⁻²	Liver	5.0 × 10⁻²	20	8.3 × 10³
$_{53}I^{135}$	Iodine-135	1.2 × 10⁻²	10⁻⁷	4 × 10⁻⁸	1.3 × 10⁻¹	Thyroid	*1.8 × 10⁻¹	0.3	3.48 × 10⁶
$_{30}Zn^{65}$	Zinc-65	1.2 × 10⁻¹	2 × 10⁻⁸	4 × 10⁻⁸	5.5 × 10⁻²	Prostate	*1.8 × 10⁻¹	60	8.2 × 10³
$_{83}Bi^{206}$	Bismuth-206	7.0 × 10⁻²	5 × 10⁻⁸	6 × 10⁻⁸	4.5 × 10⁻²	Kidney	*1.8 × 10⁻¹	1	9.9 × 10⁴
$_{33}As^{74}$	Arsenic-74	*1.7 × 10⁻¹	4 × 10⁻⁸	10⁻⁷	3.6 × 10⁻³	Kidney	1.3 × 10⁻²	40	1.01 × 10⁵

Table A-12-1 (Continued)

Nuclide		Insoluble form		Soluble form				Maximum permissible body burden (μc)	Specific activity c/g
		Lung Dose (rem/μc)	(MPC) a 168 hr wk μc/ml	(MPC) a 168 hr wk μc/ml	Inhalation dose (rem/μc)	Critical organ	Wound dose (rem/μc)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
${}_{52}\mathrm{Te}^{127m}$	Tellurium-127m	*1.7×10^{-1}	10^{-8}	5×10^{-8}	5.0×10^{-3}	Kidney	1.2×10^{-1}	7	9.8×10^{3}
${}_{76}\mathrm{Os}^{185}$	Osmium-185	*1.5×10^{-1}	2×10^{-8}	2×10^{-7}	6.0×10^{-3}	Kidney	1.5×10^{-2}	8	7.3×10^{3}
${}_{23}\mathrm{V}^{48}$	Vanadium-48	*1.4×10^{-1}	2×10^{-8}	6×10^{-8}	2.0×10^{-3}	Kidney	8×10^{-2}	8	1.7×10^{5}
${}_{50}\mathrm{Sn}^{113}$	Tin-113	*1.4×10^{-1}	2×10^{-8}	10^{-7}	2.8×10^{-3}	Bone	1.0×10^{-1}	30	9.7×10^{3}
${}_{26}\mathrm{Fe}^{59}$	Iron-59	*1.4×10^{-1}	2×10^{-8}	5×10^{-8}	4.0×10^{-3}	Spleen	1.3×10^{-1}	20	4.92×10^{4}
${}_{27}\mathrm{Co}^{58}$	Cobalt-58	*1.3×10^{-1}	2×10^{-8}	3×10^{-7}	2.4×10^{-3}	Total Body	6.0×10^{-3}	30	3.13×10^{4}
${}_{80}\mathrm{Hg}^{203}$	Mercury-203	5.8×10^{-2}	4×10^{-8}	2×10^{-8}	8.0×10^{-3}	Kidney	*1.3×10^{-1}	4	1.37×10^{4}
${}_{91}\mathrm{Pa}^{233}$	Protactinium-233	4.2×10^{-2}	6×10^{-8}	2×10^{-7}	*1.3×10^{-1}	Bone	5.5×10^{-2}	40	2.08×10^{4}
${}_{50}\mathrm{Sn}^{125}$	Tin-125	1.1×10^{-1}	3×10^{-8}	4×10^{-8}	3.3×10^{-3}	Bone	*1.2×10^{-1}	7	1.05×10^{5}
${}_{37}\mathrm{Rb}^{86}$	Rubidium-86	*1.2×10^{-1}	2×10^{-8}	10^{-7}	1.8×10^{-2}	Pancreas	2.4×10^{-2}	30	8.1×10^{4}
${}_{20}\mathrm{Sa}^{47}$	Calcium-47	5.7×10^{-2}	6×10^{-8}	6×10^{-8}	6.0×10^{-3}	Bone	1.1×10^{-1}	5	5.9×10^{5}
${}_{43}\mathrm{Tc}^{99}$	Technetium-99	*1.1×10^{-1}	2×10^{-8}	7×10^{-7}	3.0×10^{-3}	Kidney	6.0×10^{-3}	10	1.71×10^{-2}
${}_{39}\mathrm{Y}^{90}$	Yttrium-90	4.6×10^{-2}	3×10^{-8}	4×10^{-8}	2.6×10^{-2}	Bone	*1.0×10^{-1}	3	5.3×10^{5}
${}_{37}\mathrm{Rb}^{87}$	Rubidium-87	*1.0×10^{-1}	2×10^{-8}	2×10^{-7}	1.1×10^{-3}	Pancreas Liver	1.4×10^{-3}	200	6.6×10^{-8}
${}_{58}\mathrm{Se}^{141}$	Cerium-141	4.7×10^{-2}	5×10^{-8}	2×10^{-7}	2.2×10^{-2}	Bone	*9.0×10^{-3}	30	2.8×10^{4}
${}_{47}\mathrm{Ag}^{105}$	Silver-105	*8.8×10^{-2}	3×10^{-8}	2×10^{-7}	2.0×10^{-3}	Kidney	8.0×10^{-3}	30	3.11×10^{4}
${}_{44}\mathrm{Ru}^{103}$	Ruthenium-103	*8.2×10^{-2}	3×10^{-8}	2×10^{-7}	4.5×10^{-3}	Kidney	1.8×10^{-2}	20	3.19×10^{4}
${}_{28}\mathrm{Ni}^{59}$	Nickel-59	8.7×10^{-2}	3×10^{-7}	2×10^{-7}	3.0×10^{-3}	Bone	*8.0×10^{-3}	10^{3}	8.1×10^{-2}
${}_{38}\mathrm{Sr}^{85}$	Strontium-85	6.6×10^{-2}	4×10^{-8}	8×10^{-8}	3.0×10^{-3}	Bone	*8.0×10^{-3}	70	2.37×10^{4}
${}_{59}\mathrm{Pr}^{143}$	Praseodymium-143	4.6×10^{-2}	6×10^{-8}	10^{-7}	2.0×10^{-3}	Bone	*8.0×10^{-2}	20	6.6×10^{4}
${}_{66}\mathrm{Dy}^{166}$	Dysprosium-166	4.4×10^{-2}	7×10^{-8}	8×10^{-8}	2.0×10^{-3}	Bone	*8.0×10^{-3}	5	2.3×10^{5}
${}_{25}\mathrm{Mn}^{52}$	Manganese-52	*7.7×10^{-2}	5×10^{-8}	7×10^{-8}	1.6×10^{-3}	Pancreas	5.0×10^{-3}	5	4.42×10^{5}
${}_{45}\mathrm{Rh}^{105}$	Rhodium-105	*7.6×10^{-2}	2×10^{-7}	3×10^{-7}	7.0×10^{-4}	Kidney	2.2×10^{-3}	40	8.2×10^{5}
${}_{55}\mathrm{Cs}^{135}$	Caesium-135	*7.5×10^{-2}	4×10^{-7}	2×10^{-7}	1.5×10^{-3}	Liver	2.2×10^{-2}	200	8.8×10^{-4}
${}_{41}\mathrm{Nb}^{95}$	Niobium-95	*7.2×10^{-2}	3×10^{-8}	2×10^{-7}	1.2×10^{-3}	Bone	5.0×10^{-2}	40	3.93×10^{4}
${}_{60}\mathrm{Nd}^{147}$	Neodymium-147	3.6×10^{-2}	8×10^{-8}	10^{-7}	1.8×10^{-3}	Liver	*7.0×10^{-3}	10	8.0×10^{4}
${}_{52}\mathrm{Te}^{132}$	Tellurium-132	*6.4×10^{-2}	4×10^{-8}	7×10^{-8}	2.4×10^{-3}	Kidney	5.5×10^{-3}	3	3.06×10^{5}
${}_{74}\mathrm{W}^{185}$	Tungsten-185	*6.3×10^{-2}	4×10^{-8}	3×10^{-7}	1.1×10^{-3}	Bone	3.6×10^{-3}	30	9.7×10^{3}
${}_{6}\mathrm{C}^{14}$	Carbon-14	*6.1×10^{-2}	10^{-6}	10^{-6}	2.4×10^{-3}	Bone	2.8×10^{-3}	300	4.59
${}_{53}\mathrm{I}^{132}$	Iodine-132	5.4×10^{-2}	3×10^{-7}	8×10^{-8}	4.5×10^{-2}	Thyroid	*6.0×10^{-2}	0.3	1.05×10^{7}
${}_{74}\mathrm{W}^{181}$	Tungsten-181	*5.6×10^{-2}	4×10^{-8}	8×10^{-7}	2.8×10^{-4}	Liver	*9.0×10^{-4}	70	4.98×10^{3}
${}_{52}\mathrm{Te}^{125m}$	Tellurium-125m	*5.5×10^{-2}	4×10^{-8}	10^{-7}	1.6×10^{-3}	Kidney	3.6×10^{-2}	20	1.8×10^{4}
${}_{34}\mathrm{Se}^{75}$	Selenium-75	*5.6×10^{-2}	4×10^{-8}	4×10^{-7}	5.0×10^{-3}	Kidney	7.0×10^{-3}	96	1.44×10^{4}
${}_{30}\mathrm{Zn}^{69m}$	Zinc-69m	1.1×10^{-2}	10^{-7}	10^{-7}	1.6×10^{-3}	Prostate	*5.0×10^{-3}	0.7	3.29×10^{6}
${}_{55}\mathrm{Cs}^{136}$	Caesium-136	*4.8×10^{-2}	6×10^{-8}	10^{-7}	8.0×10^{-3}	Liver	1.2×10^{-3}	30	7.4×10^{4}
${}_{43}\mathrm{Tc}^{97m}$	Technetium-97m	*4.6×10^{-2}	5×10^{-8}	8×10^{-7}	1.5×10^{-3}	Kidney	3.0×10^{-3}	20	1.48×10^{4}
${}_{48}\mathrm{Cd}^{115}$	Cadmium-115	2.7×10^{-2}	6×10^{-8}	8×10^{-8}	1.1×10^{-3}	Liver	*4.5×10^{-3}	3	5.1×10^{5}
${}_{21}\mathrm{Sc}^{48}$	Scandium-48	*4.4×10^{-2}	5×10^{-8}	6×10^{-8}	1.5×10^{-3}	Bone	6.0×10^{-3}	9	1.49×10^{6}
${}_{57}\mathrm{La}^{140}$	Lanthanum-140	*4.4×10^{-2}	4×10^{-8}	5×10^{-8}	5.0×10^{-3}	Bone	2.0×10^{-2}	10	5.6×10^{5}
${}_{43}\mathrm{Tc}^{96}$	Technetium-96	*4.2×10^{-2}	8×10^{-8}	2×10^{-7}	2.8×10^{-3}	Kidney	5.5×10^{-3}	10	3.24×10^{5}

Table A-12-1 (Continued)

Nuclide		Insoluble form		Soluble form				Maximum per-missible body burden (μc)	Specific activity c/g
		Lung Dose (rem/μc)	(MPC) a 168 hr wk μc/ml	(MPC) a 168 hr wk μc/ml	Inhalation dose (rem/μc)	Critical organ	Wound dose (rem/μc)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$_{71}Lu^{177}$	Lutecium-177	1.4×10^{-2}	2×10^{-7}	2×10^{-7}	1.0×10^{-3}	Bone	$*4.0 \times 10^{-2}$	20	1.09×10^{5}
$_{40}Zr^{97}$	Zirconium-97	$*4.0 \times 10^{-2}$	3×10^{-8}	4×10^{-8}	4.0×10^{-3}	Bone	1.6×10^{-2}	5	1.9×10^{6}
$_{33}As^{76}$	Arsenic-76	$*3.9 \times 10^{-2}$	3×10^{-8}	4×10^{-8}	9.0×10^{-4}	Kidney	3.3×10^{-3}	20	1.56×10^{6}
$_{52}Te^{131m}$	Tellurium-131m	$*3.8 \times 10^{-2}$	6×10^{-8}	10^{-7}	8.0×10^{-3}	Kidney	1.8×10^{-3}	4	8.0×10^{5}
$_{47}Ag^{111}$	Silver-111	$*3.6 \times 10^{-2}$	8×10^{-8}	10^{-7}	2.0×10^{-3}	Kidney	8.0×10^{-3}	20	1.57×10^{5}
$_{68}Er^{169}$	Erbium-169	2.4×10^{-2}	10^{-7}	2×10^{-7}	9.0×10^{-3}	Bone	$*3.6 \times 10^{-2}$	30	8.2×10^{4}
$_{51}Sb^{122}$	Antimony-122	$*3.5 \times 10^{-2}$	5×10^{-8}	6×10^{-8}	2.2×10^{-3}	Bone	8.0×10^{-3}	20	3.9×10^{5}
$_{81}Tl^{202}$	Thallium-202	$*3.5 \times 10^{-2}$	8×10^{-8}	3×10^{-7}	5.5×10^{-3}	Kidney	1.1×10^{-2}	20	5.4×10^{4}
$_{11}Na^{24}$	Sodium-24	$*3.5 \times 10^{-2}$	5×10^{-8}	4×10^{-7}	1.3×10^{-3}	Total Body	1.8×10^{-3}	7	8.7×10^{6}
$_{53}I^{134}$	Iodine-134	2.2×10^{-3}	10^{-6}	2×10^{-7}	2.6×10^{-3}	Thyroid	$*3.3 \times 10^{-2}$	0.2	2.68×10^{7}
$_{35}Br^{82}$	Bromine-82	$*3.3 \times 10^{-2}$	6×10^{-8}	4×10^{-7}	2.0×10^{-3}	Total Body	2.6×10^{-3}	10	1.06×10^{6}
$_{39}Y^{93}$	Yttrium-93	$*3.2 \times 10^{-2}$	5×10^{-8}	6×10^{-8}	6.0×10^{-3}	Bone	2.4×10^{-3}	2	3.24×10^{6}
$_{19}K^{42}$	Potassium-42	$*3.2 \times 10^{-2}$	4×10^{-8}	7×10^{-7}	1.2×10^{-3}	Brain	1.6×10^{-3}	10	6.0×10^{6}
$_{58}Ce^{143}$	Cerium-143	$*3.2 \times 10^{-2}$	7×10^{-8}	9×10^{-8}	3.8×10^{-3}	Bone	1.5×10^{-3}	7	6.6×10^{5}
$_{16}S^{35}$	Sulphur-35	$*2.8 \times 10^{-2}$	9×10^{-8}	9×10^{-8}	9.0×10^{-3}	Testis	1.1×10^{-3}	50	4.29×10^{4}
$_{67}Ho^{166}$	Holmium-166	$*2.6 \times 10^{-2}$	6×10^{-8}	7×10^{-8}	6.0×10^{-3}	Bone	$*2.6 \times 10^{-2}$	5	6.9×10^{5}
$_{42}Mo^{99}$	Molybdenum-99	$*2.6 \times 10^{-2}$	7×10^{-8}	3×10^{-7}	9.0×10^{-3}	Kidney	1.4×10^{-2}	8	4.73×10^{5}
$_{31}Ga^{72}$	Gallium-72	$*2.5 \times 10^{-2}$	6×10^{-8}	8×10^{-8}	1.6×10^{-3}	Liver	7.0×10^{-3}	5	3.09×10^{6}
$_{27}Co^{57}$	Cobalt-57	$*4.2 \times 10^{-2}$	6×10^{-8}	10^{-6}	5.5×10^{-4}	Liver	1.1×10^{-3}	200	8.5×10^{3}
$_{38}Sr^{91}$	Strontium-91	$*2.4 \times 10^{-2}$	9×10^{-8}	2×10^{-7}	5.0×10^{-3}	Bone	1.2×10^{-3}	3	3.56×10^{6}
$_{26}Fe^{55}$	Iron-55	6.6×10^{-3}	3×10^{-7}	3×10^{-7}	7.0×10^{-3}	Spleen	$*2.4 \times 10^{-2}$	10^{3}	2.22×10^{3}
$_{56}Ba^{131}$	Barium-131	$*2.4 \times 10^{-2}$	10^{-7}	4×10^{-7}	1.1×10^{-3}	Total Body	4.0×10^{-3}	50	8.7×10^{4}
$_{59}Pr^{142}$	Prasodymium-142	$*2.4 \times 10^{-2}$	5×10^{-8}	7×10^{-8}	3.3×10^{-3}	Bone	1.3×10^{-3}	7	1.15×10^{6}
$_{79}Au^{198}$	Gold-198	$*2.3 \times 10^{-2}$	8×10^{-8}	10^{-7}	2.6×10^{-4}	Kidney	8.0×10^{-3}	20	2.45
$_{43}Tc^{97}$	Technetium-97	$*2.3 \times 10^{-2}$	10^{-7}	4×10^{-6}	5.0×10^{-4}	Kidney	1.0×10^{-3}	60	1.42×10^{-3}
$_{78}Pt^{193}$	Platinum-193	2.2×10^{-2}	10^{-7}	4×10^{-7}	6.0×10^{-3}	Kidney	$*2.2 \times 10^{-2}$	70	1.99×10^{5}
$_{66}Dy^{165}$	Dysprosium-165	$*2.2 \times 10^{-2}$	7×10^{-7}	9×10^{-7}	2.8×10^{-4}	Bone	1.1×10^{-3}	10	8.2×10^{6}
$_{75}Re^{186}$	Rhenium-186	$*2.2 \times 10^{-2}$	8×10^{-8}	2×10^{-7}	7.0×10^{-3}	Thyroid	1.5×10^{-3}	20	1.9×10^{5}
$_{75}Re^{188}$	Rhenium-188	$*2.0 \times 10^{-2}$	6×10^{-8}	10^{-7}	6.0×10^{-3}	Thyroid	1.2×10^{-2}	7	1.0×10^{6}
$_{77}Ir^{190}$	Iridium-190	$*2.0 \times 10^{-2}$	10^{-7}	4×10^{-7}	3.6×10^{-3}	Liver	1.2×10^{-3}	40	6.2×10^{4}
$_{61}Pm^{149}$	Promethium-149	$*1.9 \times 10^{-2}$	8×10^{-8}	10^{-7}	3.3×10^{-3}	Bone	1.3×10^{-3}	20	4.21×10^{5}
$_{33}As^{73}$	Arsenic-73	$*1.9 \times 10^{-2}$	10^{-7}	7×10^{-7}	1.8×10^{-3}	Kidney	7.0×10^{-3}	300	2.36×10^{4}
$_{76}Os^{191}$	Osmium-191	$*1.8 \times 10^{-2}$	10^{-7}	4×10^{-7}	2.2×10^{-3}	Kidney	5.5×10^{-3}	20	4.56×10^{4}
$_{78}Pt^{191}$	Platinum-191	$*1.7 \times 10^{-2}$	2×10^{-7}	3×10^{-7}	5.0×10^{-3}	Kidney	1.6×10^{-2}	10	2.28×10^{5}
$_{77}Ir^{194}$	Iridium-194	$*2.4 \times 10^{-2}$	5×10^{-8}	8×10^{-8}	2.0×10^{-3}	Kidney	6.0×10^{-4}	7	8.5×10^{5}
$_{75}Re^{183}$	Rhenium-183	$*4.5 \times 10^{-2}$	5×10^{-8}	9×10^{-7}	1.4×10^{-3}	Thyroid	2.8×10^{-3}	80	4.61×10^{3}
$_{70}Yb^{175}$	Ytterbium-175	9.8×10^{-3}	2×10^{-7}	2×10^{-7}	4.0×10^{-3}	Bone	$*1.6 \times 10^{-2}$	30	1.78×10^{5}
$_{74}W^{187}$	Tungsten-187	$*1.5 \times 10^{-2}$	10^{-7}	2×10^{-7}	3.3×10^{-4}	Liver	1.0×10^{-3}	30	7.0×10^{5}
$_{78}Pt^{197m}$	Platinum-197m	$*1.5 \times 10^{-2}$	2×10^{-6}	2×10^{-6}	2.0×10^{-5}	Kidney	7.0×10^{-4}	3	1.22×10^{7}
$_{63}Eu^{152}$ (9 yrs)	Europium-152 (9.2 hr)	$*1.4 \times 10^{-2}$	10^{-7}	10^{-7}	1.1×10^{-3}	Bone	4.5×10^{-3}	8	2.24×10^{6}

Table A-12-1 (Continued)

Nuclide (1)	(2)	Insoluble form: Lung Dose (rem/μc) (3)	Insoluble form: (MPC) a 168 hr wk μc/ml (4)	Soluble form: (MPC) a 168 hr wk μc/ml (5)	Soluble form: Inhalation dose (rem/μc) (6)	Soluble form: Critical organ (7)	Soluble form: Wound dose (rem/μc) (8)	Maximum permissible body burden (μc) (9)	Specific activity c/g (10)
${}_{76}\text{Os}^{193}$	Osmium-193	$^{*}1.4 \times 10^{-2}$	9×10^{-8}	10^{-7}	1.8×10^{-3}	Kidney	4.5×10^{-3}	10	5.3×10^{5}
${}_{80}\text{Hg}^{197m}$	Mercury-197m	6.6×10^{-3}	3×10^{-7}	3×10^{-7}	9.0×10^{-3}	Kidney	$^{*}1.4 \times 10^{-3}$	4	6.6×10^{5}
${}_{75}\text{Re}^{187}$	Rhenium-187	$^{*}1.4 \times 10^{-2}$	2×10^{-7}	3×10^{-6}	1.5×10^{-3}	Skin	2.8×10^{-3}	300	3.83×10^{-8}
${}_{21}\text{Sc}^{47}$	Scandium-47	$^{*}1.2 \times 10^{-2}$	2×10^{-7}	2×10^{-7}	1.5×10^{-3}	Bone	6.0×10^{-3}	50	8.2×10^{5}
${}_{38}\text{Sr}^{92}$	Strontium-92	$^{*}1.2 \times 10^{-2}$	10^{-7}	2×10^{-7}	2.4×10^{-3}	Bone	6.0×10^{-3}	8	1.26×10^{7}
${}_{39}\text{Y}^{92}$	Yttrium-92	$^{*}1.2 \times 10^{-2}$	10^{-7}	10^{-7}	2.2×10^{-3}	Bone	9.0×10^{-3}	2	9.5×10^{6}
${}_{46}\text{Pd}^{103}$	Palladium-103	1.0×10^{-2}	3×10^{-7}	5×10^{-7}	4.5×10^{-3}	Kidney	$^{*}1.2 \times 10^{-3}$	20	7.5×10^{4}
${}_{62}\text{Sm}^{153}$	Samarium-153	$^{*}1.1 \times 10^{-2}$	10^{-7}	2×10^{-7}	2.0×10^{-3}	Bone	8.0×10^{-3}	20	4.35×10^{5}
${}_{44}\text{Ru}^{105}$	Ruthenium-105	$^{*}1.0 \times 10^{-2}$	2×10^{-7}	2×10^{-7}	1.5×10^{-3}	Kidney	6.0×10^{-3}	2	6.6×10^{6}
${}_{1}\text{H}^{3}$	Hydrogen-3	$^{*}1.0 \times 10^{-2}$	4×10^{-6}	2×10^{-6}	2.4×10^{-4}	Body Tissue	2.4×10^{-4}	103	9.7×10^{3}
${}_{33}\text{As}^{77}$	Arsenic-77	$^{*}9.6 \times 10^{-3}$	10^{-7}	2×10^{-7}	2.6×10^{-4}	Kidney	1.0×10^{-3}	80	1.05×10^{6}
${}_{46}\text{Pd}^{109}$	Palladium-109	$^{*}9.2 \times 10^{-3}$	10^{-7}	2×10^{-7}	1.6×10^{-3}	Kidney	4.5×10^{-3}	7	2.12×10^{6}
${}_{64}\text{Gd}^{159}$	Gadolinium-159	$^{*}9.2 \times 10^{-3}$	10^{-7}	2×10^{-7}	1.0×10^{-3}	Bone	4.5×10^{-3}	20	1.1×10^{6}
${}_{93}\text{Np}^{239}$	Neptunium-239	7.7×10^{-3}	2×10^{-7}	3×10^{-7}	2.2×10^{-3}	Bone	9.0×10^{-3}	30	2.33×10^{5}
${}_{68}\text{Er}^{171}$	Erbium-171	$^{*}8.8 \times 10^{-3}$	2×10^{-7}	2×10^{-7}	1.0×10^{-3}	Bone	4.0×10^{-3}	9	2.35×10^{6}
${}_{25}\text{Mn}^{56}$	Manganese-56	$^{*}7.8 \times 10^{-3}$	2×10^{-7}	3×10^{-7}	1.0×10^{-3}	Pancreas	3.3×10^{-3}	2	2.17×10^{7}
${}_{79}\text{Au}^{199}$	Gold-199	$^{*}1.7 \times 10^{-3}$	3×10^{-7}	4×10^{-7}	8.0×10^{-4}	Kidney	2.8×19^{-3}	70	2.09×10^{5}
${}_{44}\text{Ru}^{97}$	Ruthenium-97	$^{*}7.2 \times 10^{-3}$	6×10^{-7}	8×10^{-7}	1.0×10^{-3}	Kidney	4.0×10^{-3}	30	5.5×10^{5}
${}_{28}\text{Ni}^{65}$	Nickel-65	$^{*}7.1 \times 10^{-3}$	2×10^{-7}	3×10^{-7}	1.3×10^{-3}	Bone	3.3×10^{-3}	4	1.88×10^{7}
${}_{80}\text{Hg}^{197}$	Mercury-197	2.7×10^{-3}	9×10^{-7}	4×10^{-7}	4.5×10^{-3}	Kidney	$^{*}7.0 \times 10^{-3}$	20	2.45×10^{5}
${}_{79}\text{Au}^{196}$	Gold-196	4.6×10^{-3}	2×10^{-7}	4×10^{-7}	2.0×10^{-4}	Kidney	$^{*}7.0 \times 10^{-3}$	40	1.20×10^{5}
${}_{78}\text{Pt}^{197}$	Platinum-197	$^{*}6.7 \times 10^{-3}$	2×10^{-7}	3×10^{-7}	1.4×10^{-4}	Kidney	4.5×10^{-3}	10	8.8×10^{5}
${}_{81}\text{Tl}^{200}$	Thallium-200	$^{*}6.7 \times 10^{-3}$	4×10^{-7}	9×10^{-7}	7.0×10^{-4}	Kidney	1.5×10^{-3}	40	5.8×10^{5}
${}_{81}\text{Tl}^{201}$	Thallium-201	$^{*}6.5 \times 10^{-3}$	3×10^{-7}	7×10^{-7}	1.3×10^{-3}	Kidney	2.8×10^{-3}	40	2.17×10^{5}
${}_{4}\text{Be}^{7}$	Beryllium-7	$^{*}5.9 \times 10^{-3}$	4×10^{-7}	2×10^{-6}	3.6×10^{-4}	Total Body	1.4×10^{-3}	600	3.51×10^{5}
${}_{52}\text{Te}^{127}$	Tellurium-127	$^{*}4.6 \times 10^{-3}$	3×10^{-7}	6×10^{-7}	5.0×10^{-4}	Kidney	1.2×10^{-3}	20	2.63×10^{6}
${}_{82}\text{Pb}^{203}$	Lead-203	4.2×10^{-3}	6×10^{-7}	9×10^{-7}	1.3×10^{-3}	Kidney	$^{*}4.5 \times 10^{-3}$	30	2.97×10^{5}
${}_{60}\text{Nd}^{149}$	Neodymium-149	$^{*}4.6 \times 10^{-3}$	5×10^{-7}	6×10^{-7}	4.5×10^{-4}	Liver	1.8×10^{-3}	3	1.05×10^{7}
${}_{90}\text{Th}^{231}$	Thorium-231	$^{*}4.0 \times 10^{-3}$	4×10^{-7}	5×10^{-7}	1.1×10^{-3}	Bone	$^{*}4.0 \times 10^{-3}$	30	5.3×10^{5}
${}_{29}\text{Cu}^{64}$	Copper-64	$^{*}4.0 \times 10^{-3}$	4×10^{-7}	7×10^{-7}	1.4×10^{-3}	Spleen	3.3×10^{-3}	10	3.83×10^{6}
${}_{27}\text{Co}^{58m}$	Cobalt-58m	$^{*}3.8 \times 10^{-3}$	3×10^{-6}	6×10^{-6}	2.2×10^{-5}	Liver	4.5×10^{-5}	10^{3}	5.9×10^{6}
${}_{14}\text{Si}^{31}$	Silicon-31	$^{*}3.5 \times 10^{-3}$	3×10^{-7}	2×10^{-6}	5.0×10^{-4}	Lung (Sol)	7.0×10^{-4}	10	3.86×10^{7}
${}_{24}\text{Cr}^{51}$	Chromium-51	$^{*}3.3 \times 10^{-3}$	8×10^{-7}	4×10^{-6}	3.3×10^{-4}	Lung	$^{*}1.3 \times 10^{-3}$	800	9.2×10^{4}
${}_{76}\text{Os}^{191m}$	Osmium-191m	$^{*}2.9 \times 10^{-3}$	3×10^{-6}	6×10^{-6}	1.1×10^{-4}	Kidney	2.6×10^{-4}	100	1.17×10^{6}
${}_{30}\text{Zn}^{69}$	Zinc-69	7.2×10^{-4}	3×10^{-6}	2×10^{-6}	9.0×10^{-4}	Prostate	$^{*}2.8 \times 10^{-3}$	0.8	5.3×10^{7}
${}_{55}\text{Cs}^{131}$	Caesium-131	$^{*}2.8 \times 10^{-3}$	10^{-6}	4×10^{-6}	5.0×10^{-4}	Liver	7.0×10^{-4}	700	1.0×10^{5}
${}_{17}\text{Cl}^{38}$	Chlorine-38	$^{*}2.7 \times 10^{-3}$	7×10^{-7}	9×10^{-7}	4.5×10^{-5}	Total Body	6.0×10^{-5}	9	1.33×10^{8}
${}_{9}\text{F}^{18}$	Fluorine-18	$^{*}2.3 \times 10^{-3}$	9×10^{-7}	2×10^{-6}	3.3×10^{-4}	Bone and Teeth	4.5×10^{-4}	20	9.3×10^{7}
${}_{49}\text{In}^{115m}$	Indium-115m	$^{*}2.2 \times 10^{-3}$	6×10^{-7}	8×10^{-7}	1.0×10^{-4}	Kidney Spleen	4.0×10^{-4}	30	6.1×10^{6}

Table A-12-1 (Continued)

Nuclide		Insoluble form		Soluble form				Maximum permissible body burden (μc)	Specific activity c/g
		Lung Dose (rem/μc)	(MPC) a 168 hr wk μc/ml	(MPC) a 168 hr wk μc/ml	Inhalation dose (rem/μc)	Critical organ	Wound dose (rem/μc)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$_{78}Pt^{193m}$	Platinum-193m	$*1.9 \times 10^{-3}$	2×10^{-6}	2×10^{-6}	5.5×10^{-4}	Kidney	1.8×10^{-3}	100	1.99×10^{8}
$_{52}Te^{129}$	Tellurium-129	$*2.1 \times 10^{-3}$	10^{-6}	2×10^{-6}	2.8×10^{-4}	Kidney	6.0×10^{-4}	5	1.97×10^{7}
$_{41}Nb^{97}$	Niobium-97	$*1.8 \times 10^{-3}$	2×10^{-6}	2×10^{-6}	1.5×10^{-4}	Bone	6.0×10^{-4}	10	2.61×10^{7}
$_{43}Tc^{96m}$	Technetium-96m	$*1.3 \times 10^{-3}$	10^{-5}	3×10^{-5}	1.8×10^{-5}	Kidney	3.6×10^{-5}	60	3.81×10^{7}
$_{32}Ge^{71}$	Germanium-71	$*1.2 \times 10^{-3}$	2×10^{-6}	4×10^{-6}	1.5×10^{-4}	Kidney	5.5×10^{-4}	100	1.61×10^{8}
$_{55}Cs^{134m}$	Caesium-134m	$*1.2 \times 10^{-3}$	2×10^{-6}	10^{-5}	5.5×10^{-5}	Liver	8.0×10^{-5}	100	7.4×10^{8}
$_{39}Y^{91m}$	Yttrium-91m	$*1.1 \times 10^{-3}$	6×10^{-6}	8×10^{-6}	2.0×10^{-4}	Bone	8.0×10^{-4}	5	4.11×10^{7}
$_{49}In^{113m}$	Indium-113m	$*8.4 \times 10^{-4}$	2×10^{-6}	3×10^{-6}	3.6×10^{-5}	Spleen Kidney	0.5×10^{-4}	30	1.6×10^{7}
$_{43}Tc^{99m}$	Technetium-99m	$*5.3 \times 10^{-4}$	5×10^{-6}	10^{-5}	1.0×10^{-5}	Total Body	2.0×10^{-5}	200	3.2×10^{8}
$_{38}Sr^{85m}$	Strontium-85m	$*1.4 \times 10^{-4}$	10^{-5}	10^{-5}	3.3×10^{-5}	Bone	8.0×10^{-5}	70	3.16×10^{7}
$_{45}Rh^{103m}$	Rhodium-103m	$*1.2 \times 10^{-4}$	2×10^{-5}	3×10^{-5}	4.0×10^{-6}	Spleen Kidney	1.2×10^{-5}	200	3.21×10^{7}
$_{86}Rn^{220}$	Radon-220	2.6×10^{-3}	10^{-7}						9.4×10^{8}
$_{36}Kr^{87}$	Krypton-87	8.4×10^{-3}	2×10^{-7}						2.77×10^{7}
$_{18}A^{41}$	Argon-41	7.6×10^{-3}	4×10^{-7}						4.25×10^{7}
$_{54}Xe^{135}$	Xenon-135	1.2×10^{-3}	10^{-6}						2.54×10^{6}
$_{36}Kr^{85m}$	Krypton-85m	4.4×10^{-3}	10^{-6}						8.4×10^{8}
$_{54}Xe^{133}$	Xenon-133	1.5×10^{-3}	3×10^{-6}						1.86×10^{5}
$_{36}Kr^{85}$	Krypton-85	2.6×10^{-1}	3×10^{-6}						3.97×10^{2}
$_{54}Xe^{131m}$	Xenon-131m	2.1×10^{-3}	4×10^{-6}						8.3×10^{4}
$_{18}Ar^{37}$	Argon-37	7.2×10^{-4}	10^{-3}						1.01×10^{5}

KEY

Columns 1 and 2	designate the nuclide.
Columns 3 and 4	refer to the nuclide in insoluble form.
Column 3	is the dose in rem to the lung following the inhalation of 1 μc of nuclide.
Column 4	is the Maximum Permissible Concentration of the insoluble nuclide in air in μc/ml for continuous occupational exposure quoted from ICRP publication 2 [2].
Columns 5, 6, 7 and 8	refer to the nuclide in soluble form.
Column 5	is the Maximum Permissible Concentration of the soluble nuclide in air in μc/ml for the continuous occupational exposure quoted from ICRP publication [2].
Column 6	is the dose in rem that will be delivered to the critical organ listed in column 6 following the inhalation of one μc of the nuclide in soluble form.
Column 7	is the critical organ for columns 6 and 8.
Column 8	is the dose in rem that will be delivered to the critical organ listed in column 6 following the injection of one μc of the soluble nuclide into the body via a wound.
Column 9	lists the minimum value of the maximum permissible body burden of the nuclide in μc quoted in ICRP publication 2 [2].
Column 10	lists the specific activity of the nuclides in c/g quoted in a comprehensive list of nuclides by one of the authors.

NOTE: * Indicates for the nuclide, which of the doses, Lung (insoluble form), Inhalation (soluble form), Wound (soluble form), is the greatest.

* Uranium enriched in uranium-235 and containing uranium-234 is in Group III (Ref. Ch. III, 3).

** Specific activity less than 0.002 μc/g; the current IAEA regulations do not require material of 0.002 μc/g or less to be regarded, for purposes of transport, as radioactive material for fission and activation products and 5,000 pCi/1 (5×10^{-9} Ci/1) for tritium. Most existing reactor facilities operate such that they fulfill these liquid effluent design objectives.

Similarly with noble gas effluents the design objectives for light water reactors were set forth as a 10 mrem/year exposure to an individual from all reactors on the site. (It was noted that if shielding and occupancy were considered,the actual exposure would be less than 5 mrem/year.) A review of current reactors indicates that most already comply with this requirement.

Normally an individual receives from natural sources such as cosmic rays and naturally occurring radioisotopes in food, water, building materials, etc., an annual radiation exposure of 125 mrem. In addition medical irradiation can add about another 50 millirem/year to the accumulated dose of the individual. Since not only reactor operations but all uses of radioactive materials are regulated to assure the safety of the public, the effluent releases indicated in the following sections contribute a relatively small addition to the normal radiation exposure of the public.

3. RADIOACTIVE WASTES FROM NUCLEAR POWER PRODUCTION

In the U.S. for some years to come the light water reactors will serve as the heat sources for the production of electrical power.

There are two general types of reactors in use, a boiling water reactor and a pressurized water reactor. Both types of reactors use a similar type of fuel, namely, an enriched uranium oxide (UO_2) which is clad with stainless steel or zircalloy. It is in the production, use and reprocessing of this fuel that most of the future radioactive wastes will be accumulated, or to a very small extent, released to the environment.

A preliminary study forecasting the radioactive wastes to be produced in the nuclear power cycle has been performed by the Pacific Northwest Laboratory(1) and the results were recently published in Report No. BNWL-B-141 entitled Data for Preliminary Demonstration Phase of the "Environment Quality Information and Planning System (EQUIPS)" dated December 1971. Much of the information in this section was extracted from this report and augmented where necessary by other published data.

(1) Mining and Mill Operations

Uranium mining operations are predominantly located in the States of Wyoming, New Mexico, Utah, Colorado and Texas. The acreage devoted to uranium mining in these and other states as of January 1, 1971 is given below.(2)

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Table A-12-2

U.S. Acreage Devoted to Uranium Mining

State	Acres
Arizona	221,000
California	436,000
Colorado	1,959,000
Idaho	21,000
Montana	386,000
Nevada	250,000
New Mexico	4,717,000
S & N Dakota	276,000
Texas	1,079,000
Utah	3,640,000
Washington	398,000
Wyoming	11,023,000
Total	24,406,000

A total of about 90,000,000 tons of ore have been shipped to the mills since the beginning of the uranium industry in this country. In 1970 there were about 2,800,000 tons of ore from open pit mines and 3,500,000 tons of ore from underground production (containing approximately 0.2 percent U_3O_8) shipped to the uranium mills.

Ores from the mines contain uranium-238 and uranium-235 which are in equilibrium with their long half-life daughter products among which are lead-210, polonium-210, radium-226 and thorium-230 and the short half-life gaseous product radon-222. The uranium is leached from the ore and is partially purified and concentrated in the milling operation. Two types of leaching processes are used, an acid leach and a carbonate leach. The amount of ore processed, its uranium content as U_3O_8, and the total curies of waste discharge into the different media have been estimated(1) for 1970, 1975, and 1980 and the data are presented in Table A-12-3.

The expected rates of U_3O_8 recovered in tons which serve as the basis for determining the radioactive waste discharges in Table A-12-2 compare favorably with the forecast data on commercial requirements from the Grand Junction Office of the AEC given in Table A-12-4.(2) The uranium ore processing mills are tabulated in Table A-12-5.

Table A-12-3

Uranium Mill Operating Quantities and Waste Discharges

	1970	1975	1980
Ore Processed (tons)			
Acid Leach	3,400,000	8,000,000	14,000,000
Carbonate Leach	1,000,000	2,500,000	4,000,000
U_3O_8 Recovered (tons)			
Acid Leach	6,480	15,200	26,000
Carbonate Leach	2,000	4,800	8,200
AEC Produced	4,010	-	-
Radioactive Waste Discharges (curies)(a)			
Acid Leach Process			
Air (^{222}Rn)	2,000(b)	4,000	7,000
Land (^{238}U ^{226}Ra ^{230}Th ^{210}Pb ^{210}Po)	7,000	16,000	30,000
Water (^{238}U ^{226}Ra ^{230}Th)	0.1	0.2	0.4
Carbonate Leach Process			
Air (^{222}Rn)	500(b)	1,000	2,000
Land (^{238}U ^{226}Ra ^{230}Th ^{210}Pb ^{210}Po)	2,000	5,000	8,000
Water (^{238}U)	0.5	0.4	0.7

(a) Total curies of ^{238}U, ^{222}Rn, ^{226}Ra, ^{230}Th, ^{210}Pb and ^{210}Po ore with an average U_3O_8 content of 0.2% was assumed to contain 515 μCi of uranium and each of the 5 daughters of interest, for a total of 3090 μCi per ton of ore.

(b) The actual distribution of ^{222}Rn in the milling process is not known. However, in the study it was assumed that all of the ^{222}Rn in secular equilibrium in the ore is released during crushing and grinding and is exhausted to the air via the ventilation system. The values shown do not include radon releases from the decay of radium in the impounded tailings.

Table A-12-4

U_3O_8 Production Forecast through 1985

Year	Tons of U_3O_8 in Concentrate	
	Annual	Cumulative
1971	6,900	6,900
1972	10,200	17,100
1973	14,000	31,100
1974	16,700	47,800
1975	18,400	66,200
1976	21,100	87,300
1977	24,400	111,700
1978	28,600	140,300
1979	31,700	172,000
1980	34,200	206,200
1981	39,300	245,500
1982	44,300	289,800
1983	49,100	338,900
1984	53,900	392,800
1985	59,300	452,100

(a) Tails assay of enrichment plant assumed to be 0.2% ^{235}U.

(b) Pu recycle assumed to start in 1974.

(c) Based on assumed fuel processing times and reactor characteristics supplied by reactor manufacturers.

Table A-12-5

Uranium Ore Processing Facilities and Nominal Capacity

	Tons/Day
Anaconda Co., Grants, New Mexico	3,000
Atlas Corp., Moab, Utah	1,500
Conoco-Pioneer Nuclear, Falls City, Texas	1,750
Cotter Corp., Canon City, Colorado	450
Dawn Mining Co., Ford, Washington	500
Federal-American Partners, Fremont Co., Wyo.	950
Humble Oil Co., Powder River Basin, Wyoming	2,000
Kerr-McGee Corp., Grants, New Mexico	7,000
Mines Development Inc., Edgemont, S. D.	650
Petrotomics Co., Carbon Co., Wyoming	1,500
Rio Algom, LaSal, Utah	500
Susquehanna-Western Inc., Falls City, Texas	1,000
Susquehanna-Western Inc., Three Rivers, Texas	1,000
Union Carbide Corp., Rifle & Uravan, Colorado	2,000
Union Carbide Corp., Natrona Co., Wyoming	1,000
United Nuclear-Homestake Partners, Grant, N. M.	3,500
Utah Const. & Mining Co., Fremont Co., Wyoming	1,200
Utah Const. & Mining Co., Shirley Basin, Wyoming	1,200
Western Nuclear Corp., Jeffrey Co., Wyo.	1,200
Total	31,900

(2) Uranium Conversion

The ore concentrates from the mill are reduced from U_3O_8 with hydrogen (hot cracked ammonia) and converted to UF_4 and finally UF_6 with anhydrous HF and elemental fluorine, respectively. The UF_6 is fractionally distilled to remove impurities. The alternate process of purifying the ore concentrate by solvent extraction prior to denitration to UO_2 and subsequent fluorination does not require a final fractional distillation of the UF_6. Scrap materials are recycled to assure maximum uranium recovery, but there is some buildup of radioisotopes on the inert fluid-bed material used in the reduction-fluorination operations as well as in the ash from the scrap recycle operation. The estimates of the waste, (1) most of which is drummed or impounded in earthen pounds , are given in Table A-12-6.

Table A-12-6

Uranium Conversion-Radioactive Waste Discharges - Curies

	1970	1975	1980
Air	-	-	-
Land - U-238	0.2	3.2	5.8
Ra-226	0.5	1.0	1.6
Th-230	15.2	27.3	46.0
Water - U-238	0.2	0.4	0.7

Note: Data does not include recycle of uranium from reprocessing which will still be a small part of the total (10%) through 1980. Recycled uranium will be converted to UF_6 at reprocessing plants.

The companies providing conversion services for U_3O_8 to UF_6 are Allied Chemical Corporation, Metropolis, Illinois (14,000 tons/year U); and Kerr-McGee Corporation, Sallisaw, Oklahoma (5,000 tons/year U).

(3) Uranium Enrichment

The enrichment of uranium in ^{235}U content is accomplished at AEC-owned gaseous diffusion plants where there is very little waste discharge because of its value. The estimates(1) for 1970 through 1980 are given in Table A-12-7. All enrichment services in the U.S. are provided by U.S. AEC-owned facilities at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio.

Table A-12-7

Uranium Enrichment - Radioactive Waste Discharges (Curies)

		1970	1975	1980
Air -	U-234	0.047	0.144	0.269
	U-235	0.002	0.006	0.011
	U-236	-	0.005	0.016
	U-238	0.045	0.126	0.228
Water -	U-234	0.366	1.120	2.100
	U-235	0.016	0.047	0.086
	U-236	0.002	0.039	0.125
	U-238	0.035	0.982	1.770

(4) Fuel Fabrication

1. UO_2 Fuel

The enriched UF_6 from the gaseous diffusion plant is converted to UO_2 by vaporization with water, the addition of NH_4OH to form ammonium diuranate and finally high temperature firing to form large pieces of UO_2. The UO_2 is pulverized and pelleted. Sintered and ground pellets are encased in stainless steel or zirconium-alloy tubes which are assembled with spacers, end pieces, etc., to form the final fuel assemblies for the power reactors. The radioactive waste discharges to environmental media from UO_2 fuel fabrication are provided in Table A-12-8. The companies providing uranium processing and fuel fabrication services are:

General Electric Co., San Jose, Calif., and Wilmington, N. C.
Westinghouse Electric Corp., Columbia, S. C., and Cheswick, Penna.
Gulf-United Nuclear Corp., Hematite, Mo., and New Haven, Conn.
Jersey Nuclear Co., Richland, Wash.
Kerr-McGee Corp., Cimarron, Okla.
Babcock & Wilcox, Lynchburg, Va., and Apollo, Penna.
Nuclear Fuel Services, Inc., Erwin, Tenn.
Combustion Engineering, Inc., Windsor, Conn.

Other companies providing partial services are:

Atomics International, Canoga Park, California
Gulf General Atomic, Inc., San Diego, California
NL Industries, Inc., Albany, New York.

Table A-12-8

UO_2 Fuel Fabrication - Radioactive Waste Discharges (Curies)

		1970	1975	1980
Air	U-234	0.140	0.441	0.661
	U-235	0.006	0.018	0.027
	U-238	0.033	0.105	0.158
Land Burial	U-234	0.002	0.007	0.011
	U-235	-	-	0.009
	U-238	-	0.002	0.002
Water	U-234	3.300	10.300	15.500
	U-235	0.100	0.400	0.600
	U-238	0.800	2.500	3.700

2. PuO_2 Fuel

Plutonium recovered in the reprocessing operation will be recycled in the mid-70's for fabrication as fuel assemblies. The waste expected from these operations is presented in Table A-12-9

The same companies that provide a capability in uranium processing and fuel fabrication provide the capability for Pu fuels.

Table A-12-9

PuO_2 Fuel Fabrication - Radioactive Waste Discharges (Curies)

		1970	1975	1980
Air		-	< 70µCi	<630µCi
Land Burial*	Pu-238	-	2,860	19,300
	Pu-239	-	579	3,850
	Pu-240	-	724	4,800
	Pu-241	-	197,500	1,331,000

*Assuming that waste is not reduced to a homogeneous, non-oxidizable form before burial.

Another study(3) predicts that the fuel fabrication industry will increase its quantity of alpha contaminated waste for land burial from 26,000 ft^3 with 5.6 kg of Pu in 1970 to 2,700,000 ft^3 with 580 kg of Pu in 1990. The quantity of Pu to land burial in 1980 was estimated to be 175 kg. This is the same order of magnitude as indicated in the above table which, if converted from curies to kilograms of Pu, indicates land burial of about 97 kg just from Pu fuel fabrication.

(5) Power Reactor Operations

Radioactive material during reactor operations is formed inside of the fuel rods due to fissioning of the contained uranium and exterior to the fuel rods due to neutron absorption of other materials including the cladding, the coolant, coolant impurities, reactor components, and boron poisons. It is primarily the radionuclides produced by the neutron absorption of these various materials that are collected by the waste treatment systems at the power facilities or that are released to the environmental media. Leakage of fission products through cladding imperfections also contributes to the radioactive waste, but the quantities are small. The estimated releases(1) of radioactive waste materials to environmental media are shown in Tables A-12-10 through A-12-12.

In addition to the amounts of solid waste consisting of spent resins, solidified liquid wastes and reactor control rods shown in Table A-12-11, there will be a significant volume of solid trash containing relatively small quantities of radioactivity. It is expected that in 1970, 1975, and 1980, there will be 60,000 ft^3 (30 Ci), 350,000 ft^3 (400 Ci), and 700,000 ft^3 (1,000 Ci) of this general trash, respectively.

Table A-12-10

Gaseous Effluents from Power Reactors* (Curies)

	Half-Life	1970	1975	1980
H-3	12.4 y	5.0×10^{1}	8.0×10^{2}	2.4×10^{3}
N-13	10.0 m	2.8×10^{3}	2.6×10^{4}	6.9×10^{4}
Ar-41	109.0 m	4.6×10^{3}	4.2×10^{4}	1.1×10^{5}
Kr-85 m	4.4 h	1.6×10^{5}	6.7×10^{5}	1.5×10^{6}
Kr-85	10.76 y	1.4×10^{2}	2.0×10^{3}	5.6×10^{3}
Kr-87	76.0 m	4.9×10^{5}	1.5×10^{6}	3.0×10^{6}
Kr-88	2.8 h	5.4×10^{5}	1.8×10^{6}	3.7×10^{7}
Xe-131	12.0 d	3.3×10^{2}	3.6×10^{3}	1.0×10^{4}
Xe-133 m	2.3 d	6.0×10^{3}	2.6×10^{4}	6.0×10^{4}
Xe-133	5.27 d	1.7×10^{5}	1.3×10^{6}	3.4×10^{6}
Xe-135 m	16.0 m	2.7×10^{5}	8.3×10^{5}	1.7×10^{6}
Xe-135	9.2 h	1.1×10^{5}	3.2×10^{5}	6.4×10^{5}
Xe-138	14.0 m	9.6×10^{5}	2.9×10^{6}	5.8×10^{6}
1-131	8.0 d	0.4	6.2	18.0
1-132	2.4 h	0.7	2.5	5.0
1-133	20.8 h	0.4	1.3	2.5
1-135	6.7 h	0.6	2.0	3.9
Total Curies to the Atmosphere		2.7×10^{6}	9.4×10^{6}	2.0×10^{7}

*Assumes minimum fission gas holdup time of 30 minutes.

Table A-12-11

Solid Waste from Power Reactors to Land Burial (Curies)

Radio-nuclide	1970		1975		1980	
	Resin and Sol. Liquids	Control Rods	Resin and Sol. Liquids	Control Rods	Resin and Sol. Liquids	Control Rods
H-3	$1.4\text{x}10^2$	$1.3\text{x}10^3$	$2.3\text{x}10^3$	$7.0\text{x}10^4$	$6.8\text{x}10^3$	$3.4\text{x}10^5$
Mn-54	$2.7\text{x}10^1$	$1.8\text{x}10^3$	$4.2\text{x}10^2$	$1.0\text{x}10^5$	$1.3\text{x}10^3$	$2.5\text{x}10^5$
Fe-55	$9.7\text{x}10^2$	$5.6\text{x}10^4$	$1.5\text{x}10^4$	$3.0\text{x}10^6$	$4.5\text{x}10^4$	$8.0\text{x}10^6$
Fe-59	-	-	4.6	-	$1.4\text{x}10^1$	-
Co-58	$6.6\text{x}10^1$	$2.0\text{x}10^2$	$1.0\text{x}10^3$	$1.2\text{x}10^4$	$3.0\text{x}10^3$	$2.9\text{x}10^4$
Co-60	$4.6\text{x}10^2$	7.0	$6.4\text{x}10^3$	$3.5\text{x}10^2$	$1.7\text{x}10^4$	$8.4\text{x}10^2$
Ni-59	-	7.0	-	$3.5\text{x}10^2$	-	$8.4\text{x}10^2$
Ni-63	$1.2\text{x}10^2$	$1.0\text{x}10^3$	$1.8\text{x}10^3$	$5.4\text{x}10^4$	$4.6\text{x}10^3$	$1.3\text{x}10^5$
Sr-89	5.8	-	$1.1\text{x}10^1$	-	$3.0\text{x}10^2$	-
Sr-90	2.4	-	$4.4\text{x}10^1$	-	$1.3\text{x}10^2$	-
Zr-95	1.7	-	$2.8\text{x}10^1$	-	$8.1\text{x}10^1$	-
Nb-95	3.6	-	$6.0\text{x}10^1$	-	$1.7\text{x}10^2$	-
Ru-103	$6.8\text{x}10^1$	-	$1.2\text{x}10^3$	-	$3.5\text{x}10^3$	-
Ru-106	$1.6\text{x}10^3$	-	$2.8\text{x}10^4$	-	$7.9\text{x}10^4$	-
Ag-108	-	$1.1\text{x}10^3$	-	$6.0\text{x}10^4$	-	$4.0\text{x}10^5$
Ag-110	-	$3.9\text{x}10^4$	-	$2.1\text{x}10^6$	-	$1.3\text{x}10^7$
Cd-109	-	$1.8\text{x}10^2$	-	$1.0\text{x}10^4$	-	$6.0\text{x}10^4$
Cd-115	-	7.0	-	$4.0\text{x}10^2$	-	$1.8\text{x}10^3$
In-114	-	2.0	-	$1.2\text{x}10^2$	-	$8.0\text{x}10^2$
Cs-134	$2.3\text{x}10^2$	-	$3.8\text{x}10^3$	-	$1.1\text{x}10^4$	-
Cs-137	$8.3\text{x}10^2$	-	$1.4\text{x}10^4$	-	$4.1\text{x}10^4$	-
Ce-141	-	-	2.0	-	6.0	-
Ce-144	7.5	-	$1.4\text{x}10^2$	-	$4.0\text{x}10^2$	-
Total Ci	$4.4\text{x}10^3$	$1.0\text{x}10^5$	$7.4\text{x}10^4$	$5.4\text{x}10^6$	$2.1\text{x}10^5$	$2.2\text{x}10^7$
Tot. cu. ft.	$3.0\text{x}10^4$	$1.2\text{x}10^2$	$1.7\text{x}10^5$	$2.3\text{x}10^3$	$3.3\text{x}10^5$	$1.35\text{x}10^4$

Table A-12-12

Liquid Waste from Power Reactors to Watercourses (Curies)

	1970	1975	1980
Co-58	2.1	6.1	18.3
Co-60	1.7	0.3	0.8
Sr-89	0.3	0.4	1.3
Mo-99	39.3	73.7	219.2
Ru-103	29.3	37.2	110.2
Ru-106	2.7	3.1	9.2
Te-132	7.1	31.6	154.5
1-131	11.1	55.7	166.6
1-132	6.5	41.5	124.1
1-133	3.4	41.2	123.5
1-135	1.3	20.1	60.2
Cs-134	1.9	0.8	2.4
Cs-137	0.9	0.5	1.5
Total curies excluding Tritium(H-3)	110	339	1010
H-3	1.7×10^4	2.7×10^5	8.0×10^5

In recent testimony at rulemaking hearings, the AEC staff(4) presented data on the releases of radioactive material in gaseous and liquid effluents from existing power reactors. This data for releases in 1970 is summarized in Table A-12-13, and provides a reasonable crosscheck for the data presented for 1970 in Tables A-12-10 and A-12-12.

It should be noted that none of the power reactor facilities listed in Table A-12-13 discharged liquid or gaseous effluents in excess of the safety limits established by their license, nor

Table A-12-13

Radioactive Waste Discharges from
Operating Nuclear Power Plants
(curies)

Facility	Liquid Effluents		Gaseous Effluents	
	Fission and Activation Products	Tritium	Noble and Activation Gases	Halogens & Particulates
Oyster Creek	18.5	22	1.1×10^{5}	0.32
Dresden 1	8.2	5	9.1×10^{5}	3.30
Nine Mile Pt.	28.0	20	9.5×10^{3}	<0.06
Dresden 2	13.0	31	2.5×10^{5}	1.60
Humboldt Bay	2.4	<7	5.4×10^{5}	0.35
San Onofre	7.6	4.8×10^{3}	4.2×10^{3}	<0.0001
Ginna	10.0	1.1×10^{2}	1.0×10^{4}	0.05
Big Rock Pt.	4.7	54	2.8×10^{5}	0.13
Conn. Yankee	6.7	7.4×10^{3}	7.0×10^{2}	0.0015
Saxton	0.01	10	2.2×10^{3}	0.15
Indian Pt. 1	7.8	4.1×10^{2}	1.8×10^{3}	0.075
Yankee	0.03	1.5×10^{3}	1.7×10^{1}	0
LaCrosse	6.4	20	9.5×10^{2}	0.063
Total Releases Ci	113	1.4×10^{4}	2.2×10^{6}	6.1

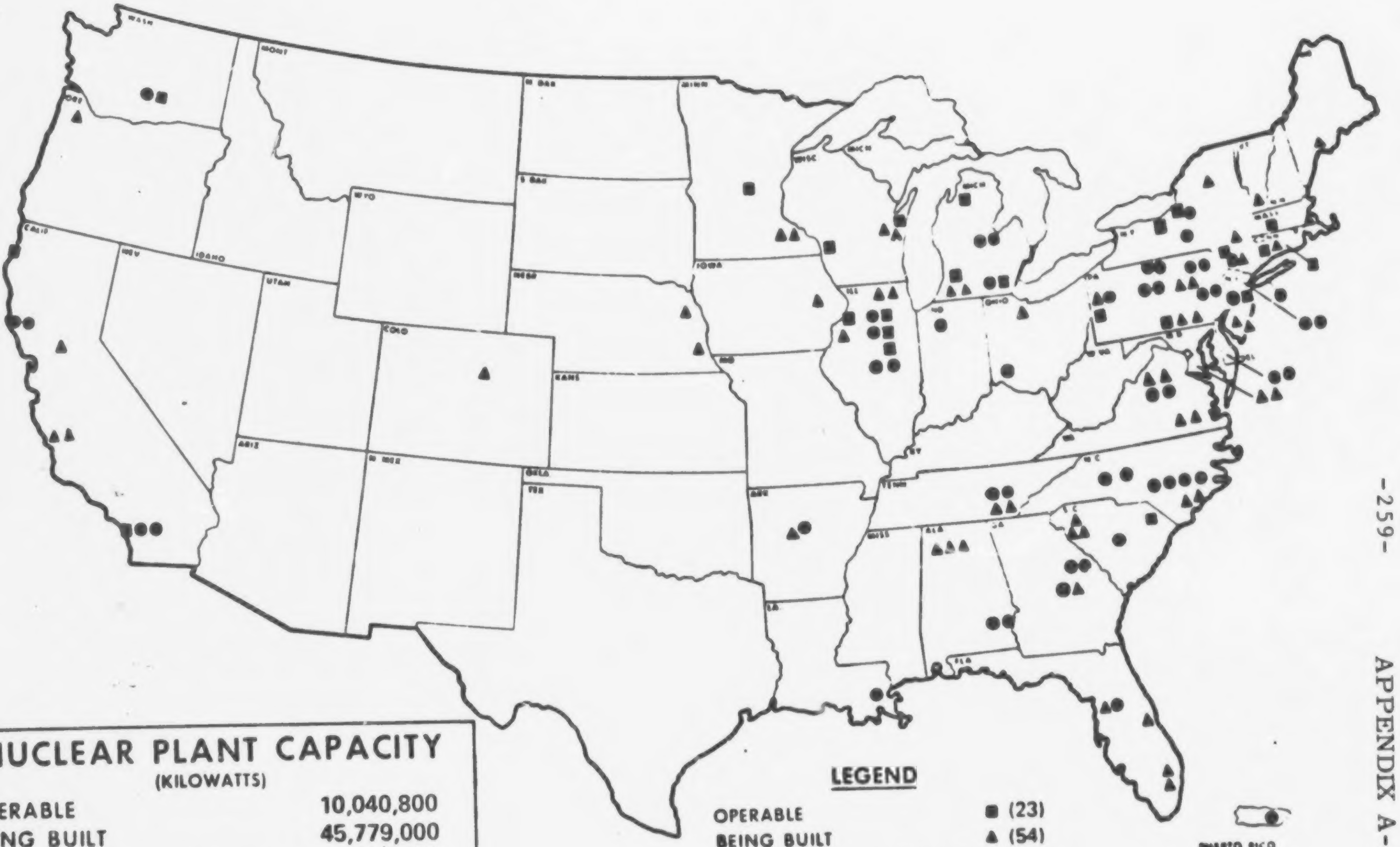
did the control of the effluent releases reflect changes necessitated by the AEC rules relating to "Control of Releases of Radioactivity to the Environment" which became effective in January 1971.

A map prepared by the U.S. Atomic Energy Commission showing the nuclear power plants that are operable, being built, and ordered but not yet under construction is presented in Figure A-12-2. Table A-12-14 indicates the features and significant milestones related to these reactors.

(6) Fuel Reprocessing

The reprocessing of spent nuclear fuel will be performed for some years to come by either the Purex process or the Aquafluor process. Inasmuch as these operations require the processing of larger quantities of more radiotoxic material than all other operations of the nuclear power cycle or nuclear industry in general, a brief description of these processes is included to identify the sources and the means of handling the radioactive wastes.

Only one commercial fuel reprocessing plant is in operation. It is operated by Nuclear Fuel Services, Inc. (NFS) at West Valley, New York, and it employs the Purex process at a nominal processing capacity of 300 metric tons of uranium per year (MTU/yr). General Electric (GE) and Allied-Gulf Nuclear Services are constructing facilities. The GE facility is in Morris, Illinois, is designed for the Aquaflor process, and will



LEGEND

OPERABLE	■ (23)
BEING BUILT	▲ (54)
PLANNED (Reactors Ordered)	● (52)

U.S. Atomic Energy Commission
December 31, 1971

(See Table A-12-14a, which follows, for description)

NUCLEAR PLANT CAPACITY
(KILOWATTS)

OPERABLE	10,040,800
BEING BUILT	45,779,000
PLANNED REACTORS ORDERED	51,571,000
TOTAL	107,390,800

TOTAL ELECTRIC UTILITY CAPACITY AS OF SEPTEMBER 30, 1971: 357,121,607 KILOWATTS

FIGURE A-12-2
Nuclear Power Reactors in the United States

Table A-12-14a
Nuclear Power Reactors in the United States

SITE	PLANT NAME	CAPACITY (Net Kilowatts)	UTILITY	INITIAL DESIGN POWER
ALABAMA				
Decatur	Browns Ferry Nuclear Power Plant: Unit 1	1,065,000	Tennessee Valley Authority	1972
Decatur	Browns Ferry Nuclear Power Plant: Unit 2	1,065,000	Tennessee Valley Authority	1973
Decatur	Browns Ferry Nuclear Power Plant: Unit 3	1,065,000	Tennessee Valley Authority	1973
Dothan	Joseph M. Farley Nuclear Plant: Unit 1	829,000	Alabama Power Co.	1975
Dothan	Joseph M. Farley Nuclear Plant: Unit 2	829,000	Alabama Power Co.	1977
ARKANSAS				
Russellville	Arkansas Nuclear One: Unit 1	820,000	Arkansas Power & Light Co.	1973
Russellville	Arkansas Nuclear One: Unit 2	920,000	Arkansas Power & Light Co.	1975
CALIFORNIA				
Humboldt Bay	Humboldt Bay Power Plant: Unit 3	68,500	Pacific Gas and Electric Co.	1963
San Clemente	San Onofre Nuclear Generating Station: Unit 1	430,000	So. Calif. Ed. & San Diego Gas & El. Co.	1967
San Clemente	San Onofre Nuclear Generating Station: Unit 2	1,140,000	So. Calif. Ed. & San Diego Gas & El. Co.	—
San Clemente	San Onofre Nuclear Generating Station: Unit 3	1,140,000	So. Calif. Ed. & San Diego Gas & El. Co.	—
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 1	1,060,000	Pacific Gas and Electric Co.	1974
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 2	1,060,000	Pacific Gas and Electric Co.	1975
Clay Station	Rancho Seco Nuclear Generation Station	804,000	Sacramento Municipal Utility District	1973
Pt. Arena	Mendocino Power Plant: Unit 1	1,128,000	Pacific Gas & Electric Co.	1978
Pt. Arena	Mendocino Power Plant: Unit 2	1,128,000	Pacific Gas & Electric Co.	1979
COLORADO				
Platteville	Ft. St. Vrain Nuclear Generating Station	330,000	Public Service Co. of Colorado	1972
CONNECTICUT				
Haddam Neck	Haddam Neck Plant	575,000	Conn. Yankee Atomic Power Co.	1967
Waterford	Millstone Nuclear Power Station: Unit 1	652,100	Northeast Utilities	1970
Waterford	Millstone Nuclear Power Station: Unit 2	828,000	Northeast Utilities	1974
DELAWARE				
*	Delmarva Unit 1	770,000	Delmarva Power & Light Co.	1979
*	Delmarva Unit 2	770,000	Delmarva Power & Light Co.	1982
FLORIDA				
Turkey Point	Turkey Point Station: Unit 3	693,000	Florida Power & Light Co.	1971
Turkey Point	Turkey Point Station: Unit 4	693,000	Florida Power & Light Co.	1972
Red Level	Crystal River Plant: Unit 3	825,000	Florida Power Corp.	1973
Red Level	Crystal River Plant: Unit 4	897,000	Florida Power Corp.	1978
Ft. Pierce	Hutchinson Island: Unit 1	800,000	Florida Power and Light Co.	1974
GEORGIA				
Baxley	Edwin I. Hatch Nuclear Plant: Unit 1	786,000	Georgia Power Co.	1973
Baxley	Edwin I. Hatch Nuclear Plant: Unit 2	786,000	Georgia Power Co.	1976
Hancock Landing	Alvin W. Vogtle, Jr. Plant: Unit 1	1,100,000	Georgia Power Co.	1978
Hancock Landing	Alvin W. Vogtle, Jr. Plant: Unit 2	1,100,000	Georgia Power Co.	1979
ILLINOIS				
Morris	Dresden Nuclear Power Station: Unit 1	200,000	Commonwealth Edison Co.	1960
Morris	Dresden Nuclear Power Station: Unit 2	809,000	Commonwealth Edison Co.	1970
Morris	Dresden Nuclear Power Station: Unit 3	809,000	Commonwealth Edison Co.	1971
Zion	Zion Nuclear Plant: Unit 1	1,050,000	Commonwealth Edison Co.	1972
Zion	Zion Nuclear Plant: Unit 2	1,050,000	Commonwealth Edison Co.	1973
Cordova	Quad-Cities Station: Unit 1	809,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1971
Cordova	Quad-Cities Station: Unit 2	809,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1972
Seneca	LaSalle Co. Nuclear Station: Unit 1	1,078,000	Comm. Ed. Co.-Ia.	1975
Seneca	LaSalle Co. Nuclear Station: Unit 2	1,078,000	Comm. Ed. Co.-Ia.	1976
*	—	1,100,000	Comm. Edison Co.	1978
*	—	1,100,000	Comm. Edison Co.	1979
INDIANA				
Dune Acres	Bailly Generating Station	660,000	Northern Indiana Public Service Co.	1976
IOWA				
Cedar Rapids	Duane Arnold Energy Center: Unit 1	529,700	Iowa Electric Light and Power Co.	1973
LOUISIANA				
Taft	Waterford Generating Station: Unit 1	1,165,000	Louisiana Power & Light Co.	1976
MAINE				
Wiscasset	Maine Yankee Atomic Power Plant	790,000	Maine Yankee Atomic Power Co.	1972
MARYLAND				
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 1	845,000	Baltimore Gas and Electric Co.	1973
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 2	845,000	Baltimore Gas and Electric Co.	1974
MASSACHUSETTS				
Rowe	Yankee Nuclear Power Station	175,000	Yankee Atomic Electric Co.	1961
Plymouth	Pilgrim Station	655,000	Boston Edison Co.	1972
MICHIGAN				
Big Rock Point	Big Rock Point Nuclear Plant	70,300	Consumers Power Co.	1963
South Haven	Palisades Nuclear Power Station	700,000	Consumers Power Co.	1971
Lagoona Beach	Enrico Fermi Atomic Power Plant: Unit 1	60,900	Detroit Edison Co.	1970
Lagoona Beach	Enrico Fermi Atomic Power Plant: Unit 2	1,123,000	Detroit Edison Co.	1974
Bridgman	Donald C. Cook Plant: Unit 1	1,054,000	Indiana & Michigan Electric Co.	1973
Bridgman	Donald C. Cook Plant: Unit 2	1,060,000	Indiana & Michigan Electric Co.	1974
Midland	Midland Nuclear Power Plant: Unit 1	492,000	Consumers Power Co.	1976
Midland	Midland Nuclear Power Plant: Unit 2	818,000	Consumers Power Co.	1977
MINNESOTA				
Monticello	Monticello Nuclear Generating Plant	545,000	Northern States Power Co.	1971
Red Wing	Prairie Island Nuclear Generating Plant: Unit 1	530,000	Northern States Power Co.	1972
Red Wing	Prairie Island Nuclear Generating Plant: Unit 2	530,000	Northern States Power Co.	1974
NEBRASKA				
Fort Calhoun	Ft. Calhoun Station: Unit 1	457,400	Omaha Public Power District	1973
Brownville	Cooper Nuclear Station	778,000	Nebraska Public Power District and Iowa Power and Light Co.	1973

Table A-12-14a (Continued)

SITE	PLANT NAME	CAPACITY (Net Kilowatts)	UTILITY	INITIAL DESIGN POWER
NEW JERSEY				
Toms River	Oyster Creek Nuclear Power Plant Unit 1	650,000	Jersey Central Power & Light Co.	1969
Forked River	Forked River Generating Station Unit 1	1,140,000	Jersey Central Power & Light Co.	1977
Salem	Salem Nuclear Generating Station Unit 1	1,090,000	Public Service Electric and Gas, N. J.	1973
Salem	Salem Nuclear Generating Station Unit 2	1,115,000	Public Service Electric and Gas, N. J.	1974
Bordentown	Newbold Nuclear Generating Station Unit 1	1,088,000	Public Service Electric and Gas, N. J.	1975
Bordentown	Newbold Nuclear Generating Station Unit 2	1,088,000	Public Service Electric and Gas, N. J.	1977
NEW YORK				
Indian Point	Indian Point Station Unit 1	265,000	Consolidated Edison Co.	1963
Indian Point	Indian Point Station Unit 2	873,000	Consolidated Edison Co.	1972
Indian Point	Indian Point Station Unit 3	965,000	Consolidated Edison Co.	1973
Scriba	Nine Mile Point Nuclear Station Unit 1	625,000	Niagara Mohawk Power Co.	1970
Scriba	Nine Mile Point Nuclear Station Unit 2	1,100,000	Niagara Mohawk Power Co.	1977
Rochester	R. E. Ginna Nuclear Power Plant Unit 1	420,000	Rochester Gas & Electric Co.	1970
Brookhaven	Shoreham Nuclear Power Station	819,000	Long Island Lighting Co.	1975
Lansing	Bell Station	838,000	New York State Electric & Gas Co.	1978
Verplanck	Con. Ed. Nuclear #4	1,115,000	Consolidated Edison Co.	1977
Scriba	James A. Fitzpatrick Nuclear Power Plant	821,000	Power Authority of State of N. Y.	1973
NORTH CAROLINA				
Southport	Brunswick Steam Electric Plant: Unit 1	821,000	Carolina Power and Light Co.	1975
Southport	Brunswick Steam Electric Plant: Unit 2	821,000	Carolina Power and Light Co.	1974
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 1	1,150,000	Duke Power Co.	1975
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 2	1,150,000	Duke Power Co.	1977
Bonsal	Shearon Harris Plant: Unit 1	915,000	Carolina Power & Light Co.	1977
Bonsal	Shearon Harris Plant: Unit 2	915,000	Carolina Power & Light Co.	1978
Bonsal	Shearon Harris Plant: Unit 3	915,000	Carolina Power & Light Co.	1979
Bonsal	Shearon Harris Plant: Unit 4	915,000	Carolina Power & Light Co.	1980
OHIO				
Oak Harbor	Davis-Besse Nuclear Power Station	872,000	Toledo Edison-Cleveland Electric Illuminating Co.	1974
Moscow	Wm. H. Zimmer Nuclear Power Station: Unit 1	810,000	Cincinnati Gas & Electric Co.	1974
OREGON				
Prescott	Trojan Station	1,130,000	Portland General Electric Co.	1974
PENNSYLVANIA				
Peach Bottom	Peach Bottom Atomic Power Station: Unit 1	40,000	Philadelphia Electric Co.	1967
Peach Bottom	Peach Bottom Atomic Power Station: Unit 2	1,065,000	Philadelphia Electric Co.	1973
Peach Bottom	Peach Bottom Atomic Power Station: Unit 3	1,065,000	Philadelphia Electric Co.	1974
Pottstown	Limerick Generating Station: Unit 1	1,065,000	Philadelphia Electric Co.	1975
Pottstown	Limerick Generating Station: Unit 2	1,065,000	Philadelphia Electric Co.	1977
Shippingport	Shippingport Atomic Power Station: Unit 1	90,000	Duquesne Light Co.	1957
Shippingport	Beaver Valley Power Station: Unit 1	847,000	Duquesne Light Co.-Ohio Edison Co.	1973
Shippingport	Beaver Valley Power Station: Unit 2	847,000	Duquesne Light Co.-Ohio Edison Co.	1976
Middletown	Three Mile Island Nuclear Station: Unit 1	831,000	Metropolitan Edison Co.	1973
Middletown	Three Mile Island Nuclear Station: Unit 2	907,000	Jersey Central Power & Light Co.	1975
Berwick	Susquehanna Steam Electric Station: Unit 1	1,052,000	Pennsylvania Power and Light	1978
Berwick	Susquehanna Steam Electric Station: Unit 2	1,052,000	Pennsylvania Power and Light	1980
*	Philadelphia Electric Co. HTGR No. 1	1,150,000	Philadelphia Electric Co.	1979
*	Philadelphia Electric Co. HTGR No. 2	1,150,000	Philadelphia Electric Co.	1981
SOUTH CAROLINA				
Hartsville	H. B. Robinson S. E. Plant: Unit 2	700,000	Carolina Power & Light Co.	1971
Seneca	Oconee Nuclear Station: Unit 1	841,000	Duke Power Co.	1972
Seneca	Oconee Nuclear Station: Unit 2	886,000	Duke Power Co.	1972
Seneca	Oconee Nuclear Station: Unit 3	886,000	Duke Power Co.	1973
Parr	Virgil C.Summer Nuclear Station: Unit 1	900,000	South Carolina Electric & Gas Co.	1977
TENNESSEE				
Daisy	Sequoyah Nuclear Power Plant: Unit 1	1,124,000	Tennessee Valley Authority	1976
Daisy	Sequoyah Nuclear Power Plant: Unit 2	1,124,000	Tennessee Valley Authority	1974
Spring City	Watts Bar Nuclear Plant: Unit 1	1,160,000	Tennessee Valley Authority	1976
Spring City	Watts Bar Nuclear Plant: Unit 2	1,160,000	Tennessee Valley Authority	1977
VERMONT				
Vernon	Vermont Yankee Generating Station	513,900	Vermont Yankee Nuclear Power Corp.	1971
VIRGINIA				
Gravel Neck	Surry Power Station: Unit 1	788,000	Virginia Electric & Power Co.	1972
Gravel Neck	Surry Power Station: Unit 2	788,000	Virginia Electric & Power Co.	1972
Mineral	North Anna Power Station: Unit 1	845,000	Virginia Electric & Power Co.	1974
Mineral	North Anna Power Station: Unit 2	845,000	Virginia Electric & Power Co.	1975
Mineral	North Anna Power Station: Unit 3	900,000	Virginia Electric & Power Co.	1977
Mineral	North Anna Power Station: Unit 4	900,000	Virginia Electric & Power Co.	1978
WASHINGTON				
Richland	N-Reactor WPPSS Steam	800,000	Atomic Energy Commission	1966
Richland	Hanford No. 2	1,118,000	Washington Public Power Supply System	1977
WISCONSIN				
Genoa	Genoa Nuclear Generating Station	50,000	Dairyland Power Cooperative	1969
Two Creeks	Point Beach Nuclear Plant: Unit 1	497,000	Wisconsin Michigan Power Co.	1971
Two Creeks	Point Beach Nuclear Plant: Unit 2	497,000	Wisconsin Michigan Power Co.	1971
Carlton	Kewaunee Nuclear Power Plant: Unit 1	541,000	Wisconsin Public Service Co.	1972
PUERTO RICO				
Puerto De Jobos	Aguirre Nuclear Power Plant	583,000	Puerto Rico Water Resources Authority	1975
* Site not selected.				
*	–	1,175,000	Tennessee Valley Authority	1977
*	–	1,175,000	Tennessee Valley Authority	1978

Table A-12-14b

Status of Central Station Nuclear Power Reactors
Significant Milestones

	Project/Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr.	Public Annc'd	NSSS Contr. Award	Contr Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
1	Shippingport Atomic Power Station, (Pa.)	Duquesne Light Company and AEC	90	PWR	West. S&W	10/53	7/53	NA	NA	12/2/57	12/18/57	12/57	NA
2	Indian Point Station, Unit 1 (N.Y.)	Consolidated Edison Co.	265	PWR	B&W O/Vit.	2/55	2/55	3/55	5/56 3/62	8/2/62	9/16/62	1/63	10/62
3	Dresden Nuclear Power Station, Unit 1 (Ill.)	Commonwealth Edison Co.	200	BWR	GE Bech.	4/55	7/55	3/55	5/56 9/59	10/15/59	4/15/60	6/60	8/60
4	Yankee Nuclear Power Station (Mass.)	Yankee Atomic Elec. Co.	175	PWR	West. S&W	4/55	6/56	7/56	11/57 7/60	8/19/60	11/10/60	1/61	2/61
5	Enrico Fermi Atomic Power Plant, Unit 1 (Mich.)	Power Reactor Development Company	60.9	FBR	PRDC CA	4/55	3/57	1/56	8/56 5/63	8/23/63	8/5/66	10/70	
6	Pathfinder Atomic Power Plant (S.D.)	Northern States Power Company	58.5	BWR	AC PSE	2/57	5/57	3/59	5/60 3/64	3/24/64	7/25/66	9/67	a
7	Hallam Nuclear Power Facility (Neb.)	Consumers Public Power District and AEC	75	SGR	AI Bech.	4/55	9/57	2/59	7/60 8/62	8/25/62	5/29/63	7/63[b]	11/63
8	Humboldt Bay Power Plant, Unit 3 (Calif.)	Pacific Gas & Electric Company	68.5	BWR	GE Bech.	2/58	2/58	4/59	11/60 8/62	2/16/63	4/18/63	5/63	8/63
9	Elk River Nuclear Plant (Minn.)	Rural Cooperative Power Association and AEC	22	BWR	AC S&L	2/56	6/58	3/59	12/59 11/62	11/19/62	8/24/63	2/64	7/64
10	Peach Bottom Atomic Pwr Station, Unit 1 (Pa.)	Philadelphia Electric Company	40	HTGR	GGA Bech.	11/58	11/58	7/60	2/62 1/66	3/3/66	1/27/67	5/67	6/67
11	Carolinas Virginia Tube Reactor (S.C.)	Carolinas-Virginia Nuclear Power Associates, Inc.	17	HWR	West. S&W	8/57	1/59	7/59	5/60 11/62	3/30/63	12/18/63	3/65	3/64[d]
12	Piqua Nuclear Power Facility (Ohio)	City of Piqua, Ohio and AEC	11.4	OMR	AI H&N	2/56	6/59	9/58	1/60 8/62	6/10/63	11/4/63	1/64	2/64[c]
13	Big Rock Point Nuclear Plant (Mich.)	Consumers Power Company of Michigan	70.3	BWR	GE Bech.	12/59	12/59	1/60	5/60 8/62	9/27/62	12/8/62	3/63	11/65
14	Boiling Nuclear Superheater Power Station (P.R.)	Puerto Rico Water Resources Authority and AEC	16.5	BWR	Comb. J&M	6/58	1/60	12/59	7/60 4/64	4/13/64	8/14/64	9/65	f
15	Genoa Nuclear Generating Station (Wisc.)	Dairyland Power Cooperative and AEC	50	BWR	AC S&L	4/61	6/62	10/62	3/63 7/67	7/11/67	4/26/68	8/69	2/71
16	Haddam Neck Plant (Conn.)	Connecticut Yankee Atomic Power Company	575	PWR	West. S&W	12/62	12/62	9/63	5/64 6/67	7/24/67	8/7/67	12/67	1/68

* Initial or current capacity, may be lower than that authorized by license. Information on achievement of future milestones based on data furnished by utility. Actual dates in bold face type, schedule dates in light face type.

CP Construction Permit

NA Not Applicable

POL Provisional Operating License

[a] Plant was shut down October 1967; on 8/6/68 NSP announced plans to install gas fired boilers for operation summer 1969; license to possess but not operate issued May 14, 1969

[b] Shut down 9/64

[c] Plant shut down 2/66.

[d] Shut down January 1967.

[e] Shut down for repairs January 1968, operating contract terminated 12/67.

[f] Decision to decommission announced 6/68. Order to dismantle issued 8/11/69.

KEY TO AE's (Architect Engineer)

AEP	American Electric Power Service Corporation
Bech.	Bechtel
B&R	Burns and Roe
CA	Commonwealth Associates
Ebas	Ebasco
Gil	Gilbert Associates
GHDR	Gibbs, Hill, Durham & Richardson
H&N	Holmes and Narver
J&M	Jackson and Moreland
O	Owner
PSE	Pioneer Service and Engineering
S&L	Sargent and Lundy
SSC	Southern Services Company
S&W	Stone and Webster
UEC	United Engineers and Constructors
Vit.	Vitro

KEY TO NSSS's (Nuclear Steam System Supplier)

AC	Allis-Chalmers
AI	Atomics International
B&W	Babcock & Wilcox
Comb.	Combustion Engineering
GE	General Electric
GGA	Gulf General Atomic
PRDC	Power Reactor Development Company
West.	Westinghouse

12/1/71

Table A-12-14b (Continued)

	Project/Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr.	Public Annc'd	NSSS Contr. Award	Contr. Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
	San Onofre Nuclear Gen. Station, Unit I (Calif.)	Southern Calif. Edison & San Diego Gas & Elec. Co.	430	PWR	West. Bech.	4/60	1/63	2/63	3/64 3/67	6/14/67	7/16/67	9/67	1/68
	N Reactor/WPPSS (Wash.)[9]	Washington Public Power Supply System and AEC	790	GR	Burns & Roe	4/62	4/63	NA	NA	12/31/63	4/8/66	7/66	
	Nine Mile Point Nuclear Station, Unit 1 (N.Y.)	Niagara Mohawk Power Corporation	626	BWR	GE O	7/63	10/63	3/64	4/65 8/69	9/5/69	11/9/69	1/70	12/69
	Oyster Creek Nuclear Power Plant, Unit 1 (N.J.)	Jersey Central Power & Light Company	650	BWR	GE B&R	5/63	12/63	3/64	12/64 4/69	5/3/69	9/23/69	12/69	12/69
	Dresden Nuclear Power Station, Unit 2 (Ill.)	Commonwealth Edison Company	809	BWR	GE S&L	2/65	2/65	4/65	1/66 12/69	1/7/70	4/13/70	10/70	8/70
	Fort St. Vrain Nuclear Generating Sta. (Colo.)	Public Service Company of Colorado	330	HTGR	GGA S&L	3/65	3/65	10/66	9/68	3/72		7/72	7/72
	R. E. Ginna Nuclear Power Plant, Unit 1 (N.Y.)	Rochester Gas & Electric Company	420	PWR	West. Gil.	8/65	8/65	11/65	4/66 9/69	11/9/69	12/2/69	3/70	7/70
	Pilgrim Station (Mass.)	Boston Edison Company	655	BWR	GE Bech.	8/65	8/65	6/67	8/68	12/71		3/72	4/72
5	Millstone Nuclear Power Station, Unit 1 (Conn.)	The Millstone Point Company	652.1	BWR	GE Ebasco	4/65	9/65	11/65	5/66 10/70	10/26/70	11/29/70	12/70	3/71
6	Indian Point Station Unit 2 (N.Y.)	Consolidated Edison Company	873	PWR	West. UEC	11/65	11/65	12/65	10/66 10/71	2/72		5/72	6/72
27	Turkey Point Station, Unit 3 (Fla.)	Florida Power and Light Company	693	PWR	West. Bech.	11/65	11/65	3/66	4/67	12/71		3/72	3/72
28	Dresden Nuclear Power Station, Unit 3 (Ill.)	Commonwealth Edison Company	809	BWR	GE S&L	1/66	1/66	2/66	10/66 1/71	1/31/71	7/22/71	11/71	11/71
29	Palisades Plant (Mich.)	Consumers Power Company of Michigan	700	PWR	Comb. Bech.	1/66	1/66	6/66	3/67 3/71	5/24/71			
30	H. B. Robinson S. E. Plant, Unit 2 (S.C.)	Carolina Power and Light Company	700	PWR	West. Ebasco	1/66	1/66	7/66	4/67 8/70	9/20/70	9/26/70	2/71	3/71
31	Point Beach Nuclear Plant, Unit 1 (Wisc.)	Wisconsin Elec Pwr Co and Wisc-Mich Pwr Co	497	PWR	West. Bech.	2/66	2/66	8/66	7/67 10/70	11/2/70	11/6/70	4/71	12/70
32	Monticello Nuclear Generating Plant (Minn.)	Northern States Power Company	545	BWR	GE Bech.	4/66	4/66	8/66	6/67 9/70	12/10/70	3/5/71	6/71	6/71
33	Quad Cities Station, Unit 1 (Ill.)	Com. Edison–Iowa–Illinois Gas & Electric	809	BWR	GE S&L	4/66	4/66	5/66	2/67 9/71	10/25/71		11/71	12/71
34	Browns Ferry Nuclear Pwr Plant, Unit 1 (Ala.)	Tennessee Valley Authority	1065	BWR	GE O	6/66	6/66	7/66	5/67	2/72		10/72	10/72
35	Browns Ferry Nuclear Pwr Plant, Unit 2 (Ala.)	Tennessee Valley Authority	1065	BWR	GE O	6/66	6/66	7/66	5/67	2/73		10/73	7/73
36	Oconee Nuclear Station, Unit 1 (S.C.)	Duke Power Company	841	PWR	B&W O	7/66	7/66	11/66	11/67	12/71		2/72	3/72
37	Oconee Nuclear Station, Unit 2 (S.C.)	Duke Power Company	886	PWR	B&W O	7/66	7/66	11/66	11/67	11/72		1/73	2/73
38	Quad Cities Station, Unit 2 (Ill.)	Com. Edison–Iowa–Illinois Gas & Electric	809	BWR	GE S&L	7/66	7/66	8/66	2/67	12/71		2/72	3/72
39	Peach Bottom Atomic Pwr Station, Unit 2 (Pa.)	Philadelphia Electric Co. PSE&GE, ACEC, DP&LC	1065	BWR	GE Bech.	5/66	8/66	2/67	1/68	10/72		2/73	3/73
40	Peach Bottom Atomic Pwr Station, Unit 3 (Pa.)	Philadelphia Electric Co. PSE&GE, ACEC, DP&LC	1065	BWR	GE Bech.	5/66	8/66	2/67	1/68	11/73		3/74	4/74
41	Salem Nuclear Generating Station, Unit 1 (N.J.)	Public Service Elec & Gas Co., PEC, ACEC, DP&LC	1090	PWR	West. O	5/66	8/66	12/66	9/68	2/74		8/74	10/74

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[9] AEC owns reactor. WPPSS the generating facilities with Burns & Roe the contractor for WPPSS

Table A-12-14b (Continued)

	Project/Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr.	Public Ann'd	NSSS Contr. Award	Contr. Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
42	Vermont Yankee Generating Station (Vt.)	Vermont Yankee Nuclear Power Corporation	513.9	BWR	GE Ebasco	12/65	8/66	11/66	12/67	11/71		12/71	1/72
43	Fort Calhoun Station, Unit 1 (Nebr.)	Omaha Public Power District	457.4	PWR	Comb. GHDR	6/66	10/66	4/67	6/68	3/73		5/73	5/73
44	Surry Power Station, Unit 1 (Va.)	Virginia Electric & Power Company	788	PWR	West. S&W	6/66	10/66	3/67	6/68	3/72		6/72	6/72
45	Surry Power Station, Unit 2 (Va.)	Virginia Electric & Power Company	788	PWR	West. S&W	10/66	10/66	3/67	6/68	10/72		12/72	12/72
46	Diablo Canyon Nuc Power Plant, Unit 1 (Calif.)	Pacific Gas & Electric Company	1060	PWR	West. O	9/66	11/66	1/67	4/68	10/73		1/74	5/74
47	Three Mile Island Nuclear Station, Unit 1 (Pa.)	Metropolitan Edison Co.	831	PWR	B&W Gil.	11/66	11/66	5/67	5/68	5/73		9/73	11/73
48	Bailly Generating Station (Ind.)	Northern Indiana Public Service Company	660	BWR	GE S&L	1/67	1/67	8/70					2/76
49	Crystal River Plant, Unit 3 (Fla.)	Florida Power Corp.	825	PWR	B&W Gil.	2/67	2/67	8/67	9/68	2/73		8/73	9/73
50	Kewaunee Nuclear Power Plant, Unit 1 (Wisc.)	Wisconsin Group (WPSC, WP&LC, MG&EC)	541	PWR	West. PSE	2/67	2/67	8/67	8/68	8/72		10/72	12/72
51	Maine Yankee Atomic Power Plant (Maine)	Maine Yankee Atomic Power Corporation	790	PWR	Comb. S&W	1/66	2/67	9/67	10/68	2/72		5/72	5/72
52	Point Beach Nuclear Plant, Unit 2 (Wisc.)	Wisconsin Elec Pwr Co & Wisc. Mich. Power Co.	497	PWR	West. Bech.	2/67	2/67	7/67	7/68 11/71			12/71	1/72
53	Prairie Island Nuclear Gen. Plant, Unit I (Minn.)	Northern States Power Company	530	PWR	West. PSE	2/67	2/67	3/67	6/68	9/72		12/72	12/72
54	Shoreham Nuclear Power Station (N.Y.)	Long Island Lighting Co.	819	BWR	GE S&W	4/65	2/67	5/68		1/75		4/75	5/75
55	Three Mile Island Nuclear Station, Unit 2 (Pa.)[h]	Jersey Central Power and Light Company	907	PWR	B&W B&R	2/67	2/67	4/68	11/69	1/75		3/75	5/75
56	Zion Station, Unit I (Ill.)	Commonwealth Edison Company	1050	PWR	West. S&L	2/67	2/67	7/67	12/68	4/72		7/72	8/72
57	Arkansas Nuclear One, Unit 1 (Ark.)	Arkansas Power and Light Company	820	PWR	B&W Bech.	4/67	4/67	11/67	12/68	4/73		9/73	9/73
58	Cooper Nuclear Station (Nebr.)	Nebraska Public Power District	778	BWR	GE B&R	6/66	4/67	7/67	6/68	12/72		3/73	4/73
59	Indian Point Station, Unit 3 (N.Y.)	Consolidated Edison Company	965	PWR	West. UEC	4/67	4/67	4/67	8/69	6/73		1/74	3/74
60	Turkey Point Station, Unit 4 (Fla.)	Florida Power and Light Company	693	PWR	West. Bech.	11/65	4/67	3/66	4/67	4/72		7/72	7/72
61	Calvert Cliffs Nuclear Power Plant, Unit 1 (Md.)	Baltimore Gas and Electric Company	845	PWR	Comb. Bech.	5/67	5/67	1/68	7/69	8/72		1/73	1/73
62	Calvert Cliffs Nuclear Power Plant, Unit 2 (Md.)	Baltimore Gas and Electric Company	845	PWR	Comb. Bech.	5/67	5/67	1/68	7/69	7/73		1/74	1/74
63	Oconee Nuclear Station, Unit 3 (S.C.)	Duke Power Company	886	PWR	B&W O	5/67	5/67	4/67	11/67	8/73		10/73	11/73
64	Salem Nuclear Generating Station, Unit 2 (N.J.)	Public Service Elec & Gas Co., PEC, ACEC, DP&LC	1115	PWR	West. O	5/66	5/67	10/67	9/68	9/74		3/75	5/75
65	Bell Station[i] (N.Y.)	New York State Electric and Gas Corp.	838	BWR	GE UEC	3/67	6/67	3/68					1978
66	Browns Ferry Nuclear Pwr Plant, Unit 3 (Ala.)	Tennessee Valley Authority	1065	BWR	GE O	6/67	6/67	7/67	7/68	11/73		4Q/73	2/74

[h] This unit originally planned as Oyster Creek 2; transfer to Three Mile Island Site announced by GPU 12/31/68.

[i] Indefinite postponement announced by utility on 4/11/69.

Table A-12-14b (Continued)

	Project Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr.	Public Annc'd	NSSS Contr. Award	Contr. Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
67	Prairie Island Nuclear Gen. Plant, Unit 2 (Minn.)	Northern States Power Company	530	PWR	West. PSE	6/67	6/67	3/67	6/68	2/74		5/74	5/74
	Donald C. Cook Plant, Unit I (Mich.)	Indiana & Michigan Electric Co.	1054	PWR	West. AEP	12/66	7/67	12/67	3/69	5/73		8/73	10/73
	Donald C. Cook Plant, Unit 2 (Mich.)	Indiana & Michigan Electric Co	1060	PWR	West. AEP	7/67	7/67	12/67	3/69	8/74		11/74	1/75
	Zion Station, Unit 2 (Ill.)	Commonwealth Edison Company	1050	PWR	West. S&L	7/67	7/67	8/67	12/68	1/73		4/73	5/73
	Rancho Seco Nuclear Gen. Station (Calif.)	Sacramento Municipal Utility District	804	PWR	B&W Bech.	4/66	8/67	11/67	10/68	12/72		4/73	5/73
	Beaver Valley Power Station, Unit 1 (Pa.)	Duquesne Light, Ohio Ed., and Penn. Power	847	PWR	West. S&W	9/67	9/67	1/69	6/70	5/73		10/73	12/73
	Limerick Generating Station, Unit 1 (Pa.)	Philadelphia Electric Company	1065	BWR	GE Bech	10/67	10/67	3/70		6/75		7/75	9/75
	Limerick Generating Station, Unit 2 (Pa.)	Philadelphia Electric Company	1065	BWR	GE Bech	10/67	10/67	3/70		12/76		1/77	3/77
	North Anna Power Station, Unit 1 (Va.)	Virginia Electric & Power Company	845	PWR	West. S&W	10/67	10/67	3/69	2/71	1/74		6/74	6/74
	Edwin I. Hatch Nuclear Plant, Unit I (Ga.)	Georgia Power Company	786	BWR	GE SSC /Bech	6/67	12/67	5/68	9/69	11/72		4/73	4/73
	Hutchinson Island, Unit I (Fla.)	Florida Power and Light Company	800	PWR	Comb Ebas	2/68	12/67	1/69	7/70	3/74		5/74	6/74
	Millstone Nuclear Power Station, Unit 2 (Conn.)	The Millstone Point Company	828	PWR	Comb. O/Bech	6/67	12/67	2/69	12/70	12/73		3/74	4/74
	Brunswick Steam Electric Plant, Unit 1 (N.C.)	Carolina Power and Light Company	821	BWR	GE UEC	1/68	1/68	7/68	2/70	11/74		2/75	3/75
	Brunswick Steam Electric Plant, Unit 2 (N.C.)	Carolina Power and Light Company	821	BWR	GE UEC	1/68	1/68	7/68	2/70	11/73		2/74	3/74
1	Verplanck, Unit 1 (N.Y.)	Consolidated Edison Company[1]	1115	BWR	GE O	1/68	1/68	6/69		6/77		10/77	5/78
2	Duane Arnold Energy Ctr., Unit 1 (Iowa)	Iowa Elec L&PC, Cent IPC, and Corn Belt PC	529.7	BWR	GE Bech.	2/68	2/68	11/68	6/70	8/73		9/73	12/73
3	Sequoyah Nuclear Power Plant, Unit 1 (Tenn.)	Tennessee Valley Authority	1124	PWR	West. O	4/68	4/68	10/68	5/70	10/73		10/74	4/74
34	Sequoyah Nuclear Power Plant, Unit 2 (Tenn.)	Tennessee Valley Authority	1124	PWR	West. O	4/68	4/68	10/68	5/70	6/74		40/74	12/74
85	Midland Nuclear Power Plant, Unit 1 (Mich.)	Consumers Power Company of Michigan[2]	492	PWR	B&W Bech.	12/67	5/68	1/69		11/76		1/77	5/77
86	Midland Nuclear Power Plant, Unit 2 (Mich.)	Consumers Power Company of Michigan[2]	818	PWR	B&W Bech.	12/67	5/68	1/69		11/77		1/78	5/78
87	Susquehanna Steam Elec. Station, Unit I (Pa.)	Pennsylvania Power and Light Company	1052	BWR	GE Bech.	5/67	5/68	3/71					1978
88	Susquehanna Steam Electric Station, Unit 2 (Pa.)	Pennsylvania Power and Light Company	1052	BWR	GE Bech.	5/68	5/68	3/71					1980
89	Diablo Canyon Nuc Power Plant, Unit 2 (Calif.)	Pacific Gas & Electric Company	1060	PWR	West. O	2/68	7/68	6/68	12/70	10/74		1/75	5/75
90	Enrico Fermi Atomic Power Plant, Unit 2 (Mich.)	Detroit Edison Company	1123	BWR	GE O/S&L	7/68	8/68	4/69		9/74		12/74	2/75
91	Davis-Besse Nuclear Power Station (Ohio)	Toledo Ed & Cleveland Elec. Illuminating Co.	872	PWR	B&W Bech.	2/68	10/68	7/69	3/71	7/74		11/74	12/74

[1] Consolidated Edison has an option for an identical unit at the same site (Number 5). CP applied 6/69.
[2] Consumers Midland Unit 1 will also produce 3.6 million pounds per hour of process steam; Unit 2 will provide 0.4 million pounds per hour.

Table A-12-14b (Continued)

	Project/Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr.	Public Ann'd	NSSS Contr. Award	Contr. Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
92	Trojan Nuclear Plant (Oregon)	Portland General Electric EW&EB and PP&LC	1130	PWR	West. Bech.	2/67	11/68	6/69	2/71	2/74		7/74	9/74
93	James A. FitzPatrick Nuc. Power Plant (N.Y.)[l]	Power Authority of the State of New York	821	BWR	GE S&W	8/68	12/68	12/68	5/70	1/73		4/73	[illegible]
94	Joseph M. Farley Nuclear Plant, Unit 1 (Ala.)	Alabama Power Company	829	PWR	West. SSC/Bech	5/69	5/69	10/69		10/74		2/75	4/75
95	Newbold Island Nuc Gen Station, Unit 1 (N.J.)	Public Service Electric and Gas Co.	1088	BWR	GE O	8/69	8/69	2/70		9/74		2/75	3/75
96	Newbold Island Nuc Gen Station, Unit 2 (N.J.)	Public Service Electric and Gas Co.	1088	BWR	GE O	8/69	8/69	2/70		9/76		2/77	3/77
97	Wm. H. Zimmer Nuc Power Station, Unit I (Ohio)	Cincinnati Gas & Elec Co., C&SOEC & DP&LC	810	BWR	GE S&L	3/68	9/69	4/70		6/76		9/76	10/76
98	William B. McGuire Nuclear Station, Unit 1 (N.C.)	Duke Power Company	1150	PWR	West. O	11/69	11/69	9/70		7/75		9/75	11/75
99	William B. McGuire Nuclear Station, Unit 2 (N.C.)	Duke Power Company	1150	PWR	West. O	11/69	11/69	9/70		10/76		1/77	3/77
100	Forked River Nuclear Gen. Station, Unit 1 (N.J.)[m]	Jersey Central Power and Light Co.	1140	PWR	Comb. B&R	12/68	12/69	6/70		5/76		2/77	8/77
101	North Anna Power Station, Unit 2 (Va.)	Virginia Electric & Power Company	845	PWR	West. S&W	10/67	1/70	3/69	2/71	1/75		6/75	6/75
102	San Onofre Nuclear Gen Station, Unit 2 (Calif.)[n]	Southern Calif Edison and San Diego Gas & Elec Co	1140	PWR	Comb. Bech.	1/70	1/70	5/70					
103	San Onofre Nuclear Gen Station, Unit 3 (Calif.)[n]	Southern Calif Edison and San Diego Gas & Elec Co	1140	PWR	Comb. Bech.	1/70	1/70	5/70					
104	Edwin I Hatch Nuclear Plant, Unit-2 (Ga.)	Georgia Power Company	786	BWR	GE SSC /Bech	2/70	2/70	7/70					1976
105	Aguirre Nuclear Power Plant (P.R.)	Puerto Rico Water Resources Authority	583	PWR	West. GHDR	5/70	5/70	11/70		7/75		9/75	1/76
106	Arkansas Nuclear One, Unit 2 (Ark.)	Arkansas Power and Light Company	920	PWR	Comb. Bech	5/70	5/70	9/70		5/75		10/75	10/75
107	LaSalle County Nuclear Station, Unit 1 (Ill.)	Commonwealth Edison Co.	1078	BWR	GE S&L	3/70	5/70	11/70		1/77		4/77	5/77
108	LaSalle County Nuclear Station, Unit 2 (Ill.)	Commonwealth Edison Co.	1078	BWR	GE S&L	3/70	5/70	11/70		1/78		4/78	5/78
109		Tennessee Valley Authority	1175	PWR	B&W	8/70	8/70			3/77		5/77	7/77
110		Tennessee Valley Authority	1175	PWR	B&W	8/70	8/70			12/77		2/78	4/78
111	Watts Bar Nuclear Plant, Unit 1 (Tenn.)	Tennessee Valley Authority	1169	PWR	West. O	8/70	8/70	5/71		3/76		6/76	8/76
112	Watts Bar Nuclear Plant, Unit 2 (Tenn.)	Tennessee Valley Authority	1169	PWR	West. O	8/70	8/70	5/71		12/76		3/77	5/77
113	Waterford Generating Station, Unit 3 (La.)	Louisiana Power and Light Company	1165	PWR	Comb. Ebas.	9/70	9/70	12/70		7/76		9/76	1/77
114	Jos. M. Farley Nuclear Plant, Unit 2 (Ala.)	Alabama Power Company	829	PWR	West. SSC/ Bech	6/70	12/70	6/70		10/76		2/77	4/77
115	Mendocino Power Plant, Unit 1 (Calif.)	Pacific Gas & Electric Co.	1128	BWR	GE O	2/71	2/71	8/71		1/78		3/78	6/78
116	Mendocino Power Plant, Unit 2 (Calif.)	Pacific Gas & Electric Co.	1128	BWR	GE O	2/71	2/71	8/71		1/79		3/79	6/79

[l] PASNY took over Niagara Mohawk contract for Easton Plant announced and contracted in 1968.

[m] Jersey Central has an option for another unit of same size.

[n] Schedule indefinite pending resolution of seismology, geology and environmental conditions.

Table A-12-14b (Continued)

	Project Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr	Public Ann'd	NSSS Contr Award	Constr Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec	Initial Design Power*	Commercial Oper.*
117	Virgil C. Summer Nuclear Sta. Unit 1 (S.C.)	South Carolina Electric & Gas Co.	900	PWR	West. Gil.	2/71	2/71	8/71		7/76		1/77	1/77
118	WPPSS Nuclear Project No. 2 (Wash.)	Washington Public Power Supply System	1103	BWR	GE B&R	2/67	3/71	8/71		4/77		7/77	9/77
9	Shearon Harris Station, Unit 1 (N.C.)	Carolina Power & Light Co.	915	PWR	West. Ebas.	4/71	4/71	9/71		10/76		1/77	4/77
0	Shearon Harris Station, Unit 2 (N.C.)	Carolina Power & Light Co.	915	PWR	West. Ebas.	4/71	4/71	9/71					1978
21	Shearon Harris Station, Unit 3 (N.C.)	Carolina Power & Light Co.	915	PWR	West. Ebas.	4/71	4/71	9/71					1979
22	Shearon Harris Station, Unit 4 (N.C.)	Carolina Power & Light Co.	915	PWR	West. Ebas.	4/71	4/71	9/71					1980
23	COMED/WEST 1 (Ill.)	Commonwealth Edison Co.	1100	PWR	West S&L	4/71	4/71			6/78		9/78	10/78
124	COMED/WEST 2 (Ill.)	Commonwealth Edison Co.	1100	PWR	West. S&L	4/71	4/71			6/79		9/79	10/79
125	North Anna Power Station, Unit 3 (Va.)	Virginia Electric & Power Co.	900	PWR	B&W S&W	4/71	4/71	9/71					1977
126	North Anna Power Station, Unit 4 (Va.)	Virginia Electric & Power Co.	900	PWR	B&W S&W	4/71	4/71	9/71					1978
127	Crystal River Plant, Unit 4 (Fla.)	Florida Power Corp.	897	PWR	West. Gil.	8/71	8/71						1978
128	Alvin W. Vogtle Nuclear Plant, Unit 1 (Ga.)	Georgia Power Co.	1100	PWR	West SSC/ Bech.	9/71	9/71						1978
129	Alvin W. Vogtle Nuclear Plant, Unit 2 (Ga.)	Georgia Power Co.	1100	PWR	West SSC/ Bech.	9/71	9/71						1979
130	Beaver Valley Power Station, Unit 2	Duquesne Light, Ohio Ed., and Penn. Power	847	PWR	West S&W	9/71	9/71						1978
131	Nine Mile Point Nuclear Power Station, Unit 2 (NY)	Niagara Mohawk Power Corporation	1100	BWR	GE S&W	6/71	9/71						1977
A	Malibu Nuclear Plant Unit 1 (Calif.)	Los Angeles Department of Water and Power	462			11/62		11/63					
B	Rome Point Unit 1 (RI)	Narragansett Electric Co.	950			4/66							1980
C	Seabrook Nuclear Station (N.H.)[0]	Public Serv. Co. of N.H. & United Illuminating Co.	860			3/67		4/69					
D	Bayside Generating Station (N.J.)	Atlantic City Electric Company	1000			6/67							1980
E	Hollister Ranch (Calif.)	Southern California Edison Company	1000			6/67							198
F	(Oregon)	Pacific Power and Light Company	1000			3/68							1977
G	(Wash.)	Seattle City Light and Snohomish County PUD	1000			4/69							1979
H	Virgil C. Summer Nuclear Sta. Unit 2 (S.C.)	South Carolina Electric & Gas Co.	900		S&W	2/71							1981
I	Unit 1, (N.J.)	Public Service Electric & Gas Co.	1100			5/71							1978
J	Unit 2 (N.J.)	Middle South Utility System	1100			5/71							1980
L	Unit 1	Middle South Utility System	1250			8/71							1979
M	Unit 2	Middle South Utility System	1250			8/71							1980

[0] Indefinite postponement announced by utility on 11/13/69; August 1968 contract with Westinghouse terminated in May 1970.

Table A-12-14b (Continued)

	Project Location	Owner	Cap.* Net (MWe)	Type	NSSS/ AE Contr	Public Annc'd	NSSS Contr Award	Constr Permit Applied	CP/ POL Issued	Initial Crit.*	First Elec.	Initial Design Power*	Commercial Oper.*
N	PEC HTGR 1	Philadelphia Electric Company	1150			8/71							1979
O	PEC HTGR 2	Philadelphia Electric Company	1150			8/71							1981
P	Perry Nuclear Power Plant, Unit 1 (OH)	Cleveland Electric Illuminating Co.	880			10/71							1980
Q	Perry Nuclear Power Plant Unit 2 (OH)	Cleveland Electric Illuminating Co.	880			10/71							1981
R	Rome Point, Unit 1 (RI)	Narragansett Electric Co.	850			1/71							1982
S	Perryman Nuclear Plant, Unit 1 (MD)	Baltimore Gas and Electric Co.	900			11/71							1979
T	Perryman Nuclear Plant, Unit 2 (MD)	Baltimore Gas and Electric Co.	900			11/71							1980
U	River Bend Station (LA)	Gulf States Utility Co.	900			11/71							1979

Table A-12-14b

Significant Milestones - Index

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57	Arkansas One No. 1
106	Arkansas One No. 2
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D	Bayside
72	Beaver Valley No. 1
130	Beaver Valley No. 2
65	Bell Station
13	Big Rock Pt.
14	BONUS
34	Browns Ferry No. 1
35	Browns Ferry No. 2
66	Browns Ferry No. 3
79	Brunswick No. 1
80	Brunswick No. 2
61	Calvert Cliffs No. 1
62	Calvert Cliffs No. 2
123	COMED/WEST No. 1
124	COMED/WEST No. 2
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11	CVTR
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46	Diablo No. 1
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3	Dresden No. 1
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28	Dresden No. 3
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94	Farley No. 1
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5	Fermi No. 1
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93	Fitzpatrick
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23	Ginna No. 1
16	Haddam Neck
7	Hallam
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119	Harris No. 1
120	Harris No. 2
121	Harris No. 3
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E	Hollister
8	Humboldt No. 3
77	Hutchinson No. 1
2	Indian Point No. 1
26	Indian Point No. 2
59	Indian Point No. 3
50	Kewaunee No. 1
15	Lacrosse
107	LaSalle No. 1
108	LaSalle No. 2
73	Limerick No. 1
74	Limerick No. 2
51	Maine Yankee
A	Malibu No. 1
98	McGuire No. 1
99	McGuire No. 2
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25	Millstone No. 1
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131	Nine Mile No. 2
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101	North Anna No. 2
125	North Anna No. 3
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O	PEC/HTGR No. 2
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Q	Perry No. 2
S	Perryman No. 1
T	Perryman No. 2
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12	Piqua
31	Point Beach No. 1
62	Point Beach No. 2
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67	Prairie Island No. 2
I	PSEG No. 1
J	PSEG No. 2
33	Quad Cities No. 1
38	Quad Cities No. 2
71	Rancho Seco
U	River Bend
30	Robinson No. 2
B	Rome Point Unit No. 1
R	Rome Point Unit No. 2
41	Salem No. 1
64	Salem No. 2
17	San Onofre No. 1
102	San Onofre No. 2
103	San Onofre No. 3
C	Seabrook
G	Seattle/Smohomish
83	Sequoyah No. 1
84	Sequoyah No. 2
1	Shippingport
54	Shoreham
117	Summer No. 1
H	Summer No. 2
44	Surry No. 1
45	Surry No. 2
87	Susquehanna No. 1
88	Susquehanna No. 2
47	Three Mile No. 1
55	Three Mile No. 2
92	Trojan No. 1
27	Turkey Point No. 3
60	Turkey Point No. 4
109	TVA/B&W No. 1
110	TVA/B&W No. 2
42	Vermont Yankee
81	Verplanck No. 1
128	Vogtle No. 1
129	Vogtle No. 2
113	Waterford No. 3
111	Watts Bar No. 1
112	Watts Bar No. 2
4	Yankee
97	Zimmer No. 1
56	Zion No. 1
70	Zion No. 2

Table A-12-14c

Nuclear Steam Supply System Contract Awards*
U.S. Central Station Reactors
No. of Units/Net MWE

YEAR	GE		WEST		B & W		COMB.		OTHER		TOTALS	
	No.	MWE	No.	MWE	No.	MWE	No.	MWE	No.	MWE	No.	MWE
THRU 1964	5	1,613.8	5	1,287.0	1	265.0	1	16.5	8	1,107.8	20	4,290.1
1965	3	2,116.1	3	1,986.0	-		-		1	330.0	7	4,432.1
1966	9	7,745.9	6	4,923.0	3	2,558.0	2	1,157.4			20	16,384.3
1967	8	7,076.0	13	10,777.0	5	4,242.0	5	4,108.0			31	26,203.0
1968	8	7,334.7	4	4,438.0	3	2,182.0	-	-			15	13,954.7
1969	3	2,986.0	3	3,129.0	-	-	1	1,140.0			7	7,255.0
1970	3	2,942.0	5	4,595.0	2	2,350.0	4	4,365.0			14	14,252.0
1971	4	4,459.0	11	10,704.0	2	1,800.0	-	-			17	16,963.0
TOTALS	43	36,273.5	50	41,839.0	16	13,397.0	13	10,786.9	9	1,437.8	131	103,734.2

*Thru 12/1/71

STATUS	NO. UNITS	CAPACITY MWE (Net)
Decommissioned	6	200.4
Operable[1]	23	10,030.8
Building[2]	54	45,779.0
Contracted	48	47,724.0
Announced	20	19,582.0
Total	151	123,316.2

[1] Achieved initial criticality, not permanently shutdown

[2] Construction permit issued

Table A-12-14d

Achievement of Commerical Operation[1] Nuclear Power Reactors Contracted for as of 12/1/71

YEAR	MWE Net		No. of Units	
	Annual	Cumulative	Annual	Cumulative
THRU 1970[2]		5,905.2	-	21
1971	3,565.1	9,470.3	6	27
1972	12,217.8	21,688.1	18	45
1973	14,350.1	36,038.2	17	62
1974	14,164.0	50,202.2	15	77
1975	13,612.0	63,814.2	14	91
1976	4,338.0	68,152.2	5	96
1977	16,409.0	84,561.2	16	112
1978	12,963.0	97,524.2	13	125
1979	4,243.0	101,767.2	4	129
1980	1,967.0	103,734.2	2	131

[1] Based on 9/30/71 schedule information reported by utilities

[2] Includes 6 plants which achieved design power in prior years but have since been permanently shutdown:
Hallam (75 MWe); Pique (11.4 MWe), CVTR (17 MWe); BONUS (16.5 MWe);
Pathfinder (58.5 MWe); Elk River (22 MWe).

have a nominal capacity of 300 MTU/yr. The Allied-Gulf facility is in Barnwell, S.C., is designed for the Purex process, and will have a nominal capacity of 1500 MTU/yr. The GE plant is expected to go into operation in late 1972, and the Allied-Gulf plant in late 1974. The forecast annual requirements for spent fuel reprocessing are 1400 MTU in 1975 and and 2800 MTU in 1980.

In both the Purex and the Aquafluor processes, the spent fuel, transported in heavily shielded casks from the reactor facilities to the reprocessing plant, is unloaded underwater and stored temporarily underwater until there is an elapsed time of about 150 days from the time of withdrawal from the reactor. This storage time allows the decay of many short, half-life fission products in the fuel. After suitable storage, the fuel assemblies are processed remotely in heavily shielded concrete cells.

To start, the fuel assembly (up to 15 ft long) is dismantled to separate the stainless steel or zircalloy fuel-bearing tubes from the remainder of the assembly. The stainless and zircalloy tubes are then chopped into small segments to expose the fuel and these segments are placed in nitric acid which dissolves the fuel and its fission products and leaves the tubing segment (hull) intact. This "chop-leach" operation produces contaminated fuel assembly hardware and hulls as solid waste, and it releases fission product gases which undergo treatment to remove radioiodines and particulates before discharge.

Next, the dissolved fuel is processed by means of solvent extraction to separate the uranium and plutonium from each other and from the fission products (high-level wastes). In the Purex operations, the fission product wastes from solvent extraction are concentrated to recover nitric acid and are stored in acid-form* in stainless steel tanks for up to five years before they have to be converted to solids in an acceptable form for ultimate disposal at a Federal Repository. In the Aquafluor process, the fission product wastes will not be stored temporarily as liquids, but will be calcined to a solid form. The calcined solids will be sealed in stainless steel cylinders which will be stored underwater to remove fission product heat.

Up through the first solvent extraction operation, the Purex and Aquafluor processes are very similar, and they vary only in subsequent purification of uranium and plutonium. The

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* Initial NFS operations have collected and stored about 500,000 gallons of neutralized fission product wastes.

Purex process uses additional solvent extraction operations to purify both the uranium and plutonium, and the Aquafluor process purifies the uranium by fluorination.

Low-level liquid wastes in the reprocessing operation are primarily the effluent from nitric acid recovery. In the case of NFS, this and other low-level aqueous waste streams are treated by scavenging, precipitation, and ion exchange before discharge to a watercourse. In the design of the GE and Allied-Gulf facilities, there is no low-level aqueous discharge to the watercourse; instead, there is an internal water recycle with a bleed-off evaporation step to maintain an equilibrium concentration of tritium in the recycled water.

The curie quantities of the fission products and the actinides in a metric ton of uranium fuel following different burnups and after different cooling times are shown in Table A-12-15. The data(5, 6) has been listed on the bases of half-lifes of the fission products and the actinides to show those that are of significance for long-term storage, and the radiogases are shown separately.

Table A-12-15

Curies of Long Half-Life Fission Products and Actinides per MTU of Fuel for Different Burnups and Cooling Times

		GE Data		ORNL Data	
Burnup - MWD/MTU SP. PWR - MW/MTU CLG. Time - Days		21,900 30 160	43,800 30 160	33,000 30 150	33,000 30 3,652
Radionuclide	**Half-Life**				
Sm 151	90 y	$1.0x10^{2}$	$1.5x10^{2}$	$1.2x10^{3}$	$5.2x10^{2}$
Cs 137	30 y	$7.2x10^{4}$	$1.4x10^{5}$	$1.1x10^{5}$	$8.5x10^{4}$
Sr 90	28 y	$5.4x10^{4}$	$8.9x10^{4}$	$7.7x10^{5}$	$6.0x10^{4}$
Eu 154	16 y	$1.3x10^{3}$	$4.0x10^{3}$	$6.8x10^{3}$	$4.5x10^{3}$
Sn 121 m	5 y	$5.0x10^{1}$	$1.0x10^{2}$	-	-
Sb 125	2.7 y	$3.8x10^{3}$	$7.6x10^{3}$	$8.1x10^{3}$	$6.9x10^{2}$
Pm 147	2.7 y	$1.7x10^{5}$	$2.1x10^{5}$	$9.9x10^{4}$	$7.9x10^{3}$
Cs 134	2.1 y	$3.2x10^{4}$	$9.5x10^{4}$	$2.1x10^{5}$	$8.3x10^{3}$
Eu 155	1.7 y	$1.6x10^{3}$	$4.0x10^{3}$	$6.4x10^{3}$	$1.6x10^{2}$
Gd 162	>1 y	$1.0x10^{2}$	$2.5x10^{2}$	$1.7x10^{2}$	-
Ru 106	1 y	$3.2x10^{5}$	$5.9x10^{5}$	$4.1x10^{5}$	$5.5x10^{2}$
Ce 144	285 d	$7.2x10^{5}$	$7.3x10^{5}$	$7.7x10^{5}$	$1.5x10^{2}$
Sn 119 m	250 d	$1.0x10^{2}$	$1.0x10^{2}$	$1.0.10^{1}$	-
Ag 110 m	249 d	$3.5x10^{2}$	$1.4x10^{3}$	$2.6x10^{2}$	-
Radiogases					
1-129	$1.6x10^{7}$y	0.02	0.04	-	-
H-3	12.4 y	-	-	$6.9x10^{2}$	$4.0x10^{2}$
Kr-85	10.8 y	$7.4x10^{3}$	$1.3x10^{4}$	$1.1x10^{4}$	$6.0x10^{3}$
Actinide					
Pu-239	$2.4x10^{4}$y			$3.3x10^{2}$	
Am-243	$\sim 1.0x10^{4}$y			$1.7x10^{1}$	
Pu-240	$6.58x10^{3}$y			$4.8x10^{2}$	
Am-241	$4.75x10^{2}$y			$2.0x10^{2}$	
Pu-238	$9.2x10^{1}$y			$2.8x10^{3}$	
Cm-244	$1.9x10^{1}$y			$2.5x10^{3}$	

The forecast[6] of the annual generation rate (Ci/yr) and the total accumulated quantities (Ci) of the significant long half-life isotopes from fuel reprocessing are shown in Table A-12-16, including the volumes of these high-level wastes if stored as liquids or as solids.

The generation rates[1, 6] of miscellaneous low-level solid wastes and of fuel hulls and hardware are given in Table A-12-17.

(7) Transportation

A good summary of transportation is given in the Nuclear Industry 1971, WASH-1174-71, by the U.S. AEC. The materials moved and the types of packages used are given in Table A-12-18 reproduced from that document.

Spent fuel shipments will require a larger tonnage of shipments than any other phase of the nuclear power cycle (i.e., until high-level waste shipments to Federal Repository are necessary) because of the massive shielding that is required during shipment. A review[8] of spent fuel shipments indicates that 73.5 percent of the known power reactor sites can be served by rail, 22 percent by truck only, and 4.5 percent by barge.

Table A-12-16

Forecast of the Generation Rates and the Total Accumulations of Long-Life Fission Products and Actinides in High-Level Wastes from Fuel Reprocessing[(e)]

Isotopes	Generation Rate[(c, d)] (curies/year)			Accumulation (curies)		
	1970	1980	1990	1970	1980	1990
H-3	$4.,0\text{x}10^4$	$2.1\text{x}10^6$	$6.2\text{x}10^6$	$4.0\text{x}10^4$	$7.3\text{x}10^6$	$3.6\text{x}10^7$
Kr-85	$6.0\text{x}10^5$	$3.3\text{x}10^7$	$9.0\text{x}10^7$	$6.0\text{x}10^5$	$1.2\text{x}10^8$	$5.7\text{x}10^8$
1-129	2.0	$1.1\text{x}10^2$	$4.4\text{x}10^2$	2.0	$4.8\text{x}10^2$	$2.7\text{x}10^3$
	As High Level Liquid or Solid Wastes					
Sr 90	$4.0\text{x}10^6$	$2.3\text{x}10^8$	$5.6\text{x}10^8$	$4.0\text{x}10^6$	$9.6\text{x}10^8$	$4.6\text{x}10^9$
C 137	$5.6\text{x}10^6$	$3.2\text{x}10^8$	$8.8\text{x}10^8$	$5.6\text{x}10^6$	$1.3\text{x}10^9$	$6.5\text{x}10^9$
Pu 238	$7.0\text{x}10^2$	$4.1\text{x}10^4$	$2.0\text{x}10^5$	$7.0\text{x}10^2$	$1.2\text{x}10^6$	$8.3\text{x}10^6$
Pu 239	$9.0\text{x}10^1$	$5.0\text{x}10^3$	$5.0\text{x}10^4$	$9.0\text{x}10^1$	$2.0\text{x}10^4$	$2.4\text{x}10^5$
Pu 240	$1.2\text{x}10^2$	$7.0\text{x}10^3$	$6.0\text{x}10^4$	$1.2\text{x}10^2$	$4.0\text{x}10^4$	$4.0\text{x}10^5$
Am 241	$9.0\text{x}10^3$	$5.0\text{x}10^5$	$4.4\text{x}10^6$	$9.0\text{x}10^3$	$2.3\text{x}10^6$	$2.3\text{x}10^7$
Am 243	$2.1\text{x}10^2$	$1.0\text{x}10^4$	$1.0\text{x}10^5$	$2.1\text{x}10^2$	$2.3\text{x}10^5$	$1.5\text{x}10^6$
Cm 244	$1.3\text{x}10^5$	$7.4\text{x}10^6$	$1.8\text{x}10^7$	$1.3\text{x}10^5$	$3.0\text{x}10^7$	$1.4\text{x}10^8$
Gals/yr if liq. [(a)]	$1.7\text{x}10^4$	$9.7\text{x}10^5$	$2.7\text{x}10^6$	$1.7\text{x}10^4$	$4.4\text{x}10^6$	$2.4\text{x}10^7$
Cu ft/yr if sol. [(b)]	$1.7\text{x}10^2$	$9.7\text{x}10^3$	$2.7\text{x}10^4$	$1.7\text{x}10^2$	$4.4\text{x}10^4$	$2.4\text{x}10^5$

(a) Assumes 100 gallons per 10,000 Mwd.

(b) Assumes 1 cu ft per 10,000 Mwd.

(c) Assumes LWR @ 33,000 Mwd/MTU, 30 Mw/MTU, 90d. clg; LMFBR @ 80,000 Mwd/Mtu, 148 Mw/MTU 30d. clg.

(d) Assumes 0.5% of Pu to waste.

(e) Assumes introduction of LMFBR in 1980.

Table A-12-17

Generation of Miscellaneous Solid Waste and Hulls and Hardware at Fuel Reprocessing Plants

	1970	1975	1980
Purex			
Miscellaneous			
Waste - ft^3	$5.1x10^{4}$	$2.2x10^{5}$	$6.3x10^{5}$
- Ci	$5.2x10^{4}$	$2.3x10^{5}$	$7.8x10^{5}$
Cladding - ft^3	-	$2.4x10^{3}$	$6.7x10^{3}$
- Ci	-	$6.5x10^{6}$	$1.8x10^{7}$
Aquafluor			
Miscellaneous			
Waste - ft^3	-	$3.6x10^{4}$	$4.5x10^{4}$
- Ci	-	$3.7x10^{4}$	$5.6x10^{4}$
Cladding - ft^3	-	$3.7x10^{2}$	$4.8x10^{2}$
- Ci	-	$1.0x10^{6}$	$1.3x10^{6}$

The total accumulation of cladding hulls and hardware by 1980 is estimated to be 40,000 cubic feet.

Table A-12-18

Material Flow in the Nuclear Fuel Cycle

Material	Point to Point Movement	Packaging
Uranium Ore Conc.	Mill to feed preparation	Drums
Normal UF_6	Feed preparation to enrichment	Press. cylinders
Enriched UF_6	Enrichment to material processing	Press. cylinders and protective packages
Enriched UO_2 Powder and Pellets	Material processing to fuel fabrication	Drums and birdcages
Fuel Assemblies	Fuel fabrication to power reactor	Protective packages and birdcages
Spent Fuel	Power reactor to reprocessor	Shielded casks
Uranyl Nitrate	Reprocessor to fuel fabrication	Tank trucks and protective packages
Plutonium Nitrate	Reprocessor to fuel fabrication	Pu containers and protective packages
Solid Fission Prod. Waste*	Reprocessor to Federal Repository	Shielded casks
Low-Level Waste	Anyone to waste burial	Drums and protective packages

* Future shipments.

Accordingly, the 22 percent served by truck only would require smaller 25-ton casks capable of being transported on load-limited highways, whereas the other sites could be serviced by larger 75-ton casks suitable for rail or barge shipments. Assuming lead-shielded shipping casks with a spent fuel payload of 0.25 MTU/ton for the small truck casks, and 0.045 MTU/ton for the large rail casks, and round-trip times of 1 week and 3 weeks, respectively, the total tons shipped round-trip and the number of casks required are shown in Table A-12-19.

Table A-12-19

Spent Fuel Shipments

Year	By Truck Tons Shipped	No. of 25-Ton Casks	By Rail Tons Shipped	No. of 75-Ton Casks
1970	1,480	1	2,940	2
1971	2,670	2	5,300	2
1972	5,020	2	9,500	4
1973	8,180	4	16,300	7
1974	12,640	5	25,200	10
1975	17,800	7	35,400	14
1976	24,900	10	49,700	19
1977	32,000	13	63,800	24
1978	40,900	17	81,400	31
1979	49,800	20	99,200	38
1980	58,700	23	116,800	44

A trend towards uranium-shielded casks could reduce the above round-trip shipment tonnages, but will not significantly affect the number of casks required. The number of spent fuel shipments in 1980 will be about 1,800.

4. RADIOACTIVE WASTES FROM MEDICAL AND INDUSTRIAL APPLICATIONS

The medical profession is rapidly developing diagnostic and therapeutic uses for both reactor-produced and cyclotron-produced radioisotopes. These uses produce relatively small quantities of radioactive waste. In diagnostic applications, whereby a patient ingests radioactive material to permit a direct measurement of an area of concern, the radioactive material is of short half-life to minimize radiation exposure of the patient. On the other hand, in the case of therapeutic treatments, radiation energy is utilized so the radioisotopes used are of high radiation energy and are long half-life well encapsulated materials, used to the very maximum before they are replaced. Replaced encapsulated materials are sometimes reused for other applications or are of such low activity they are sent to one of the six land burial sites for disposal which also service nuclear power facilities. These land burial sites are shown in Table A-12-20.

Table A-12-20

Licensed Low-Level Waste Burial Sites

Site Location	Operation	Area of Site (acres)
Richland, Wash.	Nuclear Engineering Co.	100
Beatly, Nevada	Nuclear Engineering Co.	80
Sheffield, Ill.	Nuclear Engineering Co.	27
Morehead, Ky.	Nuclear Engineering Co.	200
West Valley, N. Y.	Nuclear Fuel Services, Inc.	10
Barnwell, S. C.	Chem-Nuclear Services, Inc.	-

Table A-12-21 presents some of the radionuclides used in medical and industrial applications.

5. RADIOACTIVE WASTE FROM AEC FACILITIES

In this section, all the information provided by the Atomic Energy Commission for the purpose of inclusion in this study is presented.

(1) Radioactive Waste Management Principles and Practices

Many things are unique about the production and utilization of radioactive materials in the United States. One of the most

Table A-12-21

Radionuclides Used in Medical and Industrial Applications

Radioisotope	Emission	Half-Life
Used in Medical Diagnostic Work:		
Carbon-11	β^+	20.5 m
Nitrogen-13	β^+	10.1 m
Oxygen-15	β^+	2.1 m
Fluorine-18	β^+	1.87 m
Sulfur-37	$\beta^-\gamma$	5.0 m
Calcium-47	$\beta^-\gamma$	5.8 d
Chromium-51	γ	26.0 d
Gallium-68	$\beta^+\gamma$	68.0 m
Selinium-73	$\beta^+\gamma$	7.0 h
Technetium-99m	$\beta^-\gamma$	5.9 h
Used in Doubly Encapsulated Form of Therapy Work:		
Cobalt-60	γ	5.25 y
Strontium-90	β^-	28.0 y
Cesium-137	γ	30.0 y
Plutonium-238	α	92.0 y
Used in Doubly Encapsulated Form for Industrial Applications:		
Cobalt-60	γ	5.25 y
Strontium-90	β^-	28.0 y
Cesium-137	γ	30.0 y
Thulium-170	γ	127.0 y
Iridium-192	γ	75.0 d
Americium-241	α	475.0 y

unusual is the fact that the hazards attending the development and growth of the pertinent science and technology, which had been recognized soon after the discovery of radioactivity, were consciously and explicitly dealt with by means of operating procedures when large-scale Government activities began in the early 1940's. The hazards were also recognized by the Congress when the Atomic Energy Act was passed in 1946, as is illustrated by Section 5(c)(2) of the Act which stated that "The Commission shall not distribute any by-product material to any applicant... who is not equipped to observe or who fails to observe such safety standards to protect health as may be established by the Commission..." Likewise, Section 12(a)(2) stated that the Commission was authorized to "establish by regulation or order such standards and instructions to govern the possession and use of fissionable and by-product materials as the Commission may deem necessary or desirable to protect health or to minimize dangers from explosions and other hazards to life or property."

These statutory provisions were retained when the Act was thoroughly revised and updated in 1954 and, in addition, a basic policy statement was added to Chapter 1, Section 2: "d. The processing and utilization of source, by-product, and special nuclear material must be regulated in the national interest and in order to provide for the common defense and security and to protect the health and safety of the public." Further, Sections 53, 62, and 81 set up a framework for licensing the possession and use of special nuclear material, source material, and by-product material. A similar licensing structure was set up for production and utilization facilities by Chapter 10 of the Act.

Administration of these statutory responsibilities with respect to licensees has been implemented by issuance of Rules and Regulations, Title 10, Part 20, Standards for Protection against Radiation. Sections 20.301 through 20.305 of Part 20 apply specifically to Waste Disposal. Various other issuances are also pertinent, such as Part 30 on by-product material, Part 50 on production and utilization facilities, and Part 71, Packaging of Radioactive Material for Transport. In addition, similar requirements are laid on contractors who operate Government-owned facilities for AEC programmatic purposes. In these cases, regulations are incorporated in AEC Manual Chapter 0524, Standards for Radiation Protection.

Central to the CFR and AEC Manual regulations just referenced is one basic principle that, as mentioned above, has differentiated the nuclear industry (including the research and development phases) from other "high technology" activities that have marked the twentieth century. The environmental damage that has accompanied such major activities as transportation and electric power generation, where disposal of the waste products was allowed to follow economic principles that externalized the costs of pollution by dumping the wastes on the "commons," contrasts sharply with nuclear activities where the basic principle is to contain the wastes rather than to disperse them. Because of the relative compactness of nuclear wastes, essentially complete retention is quite practical.

This statement about containment must not be misunderstood, for it is not claimed that no radioactivity is released to the environment. But concentration and retention is the primary management technique; dilution and dispersal is a secondary tool used where concentrations are very low and volumes are high. This concept explains why AEC classifies liquid wastes primarily on the basis of penetrating radiation as low-activity or high-activity; the latter class requires retention while the former either meets appropriate standards for direct discard or can be treated (by precipitation, ion exchanges, decay-storage, etc.) to provide a discardable fraction and a fraction that is stored indefinitely under conditions similar to those required for high-activity wastes. So-called "intermediate-level" wastes are treated by the same fractionation techniques used for many low-level wastes; the major difference is that low-level wastes can often be discharged directly, after monitoring, whereas intermediate level wastes may require more than one fractionation to obtain a discardable portion. All solid radioactive wastes, whether low- or high-level with respect to external radiation hazard, are retained by storage or land burial.

In addition to the low-high dichotomy, there are other characterizations of radioactive wastes that are important. A package of solid wastes, for example, may contain potent gamma-emitting isotopes of short half-life; special procedures would be required in handling the package today, but in 10 or 100 years there may be no residual hazard. On the other hand, a package containing 10 grams of plutonium would pose no external handling hazard today, but represents such a serious potential future danger if mishandled, due to the combination of its long half-life and high toxicity per unit weight, that it must be stored under conditions that will keep it out of man's environment for extremely long periods of time.

While the rules and regulations cited above are quite detailed and the principles they seek to implement may seem quite simple and clear, it should be realized that this situation has evolved over a period of about three decades, with considerable improvement having taken place. Especially in the early days, there were expedient actions taken that did not result in exposing the public to radiation in excess of standards but which left the wastes in types of interim storage requiring eventual further effort for the provision of long-term storage. In particular, the early storage of relatively dilute and neutralized liquid wastes from nuclear fuel reprocessing has left a backlog of wastes in interim storage which cannot be handled by the technology now available for early conversion to compact solids of the concentrated acid wastes from modern reprocessing plants. Consequently, AEC does not claim to have resolved all of the technical questions on long-term storage of all types of high-level wastes, but believes the work in progress will resolve them well within the time provided by safe interim storage.

In order to devote increased management attention to the resolution of its waste handling problems, the AEC recently formed a Division of Waste Management and Transportation.

The staff is currently formalizing and scheduling a number of objectives, policies, and actions that had long been an informal part of the AEC waste management responsibility or goals to be sought. For example, high-level liquid waste storage in tanks will not henceforth be regarded as an acceptable practice for long-term storage although it has proven adequate for interim containment pending the development of policy, technology, and facilities for long-term management. As a step toward improved interim containment, additional stress is being placed on solidification for in-tank storage in a form providing reduced mobility but at the same time not precluding removal to deep underground storage or transfer to a repository. Whatever method of long-term storage is finally selected for these high-level residues, it is intended that there be high assurance of isolation from man's environment with minimal reliance on perpetual maintenance and surveillance by man.

Similar principles have been incorporated in the frame of reference applied to licensee handling of high-level liquid wastes. Under a recent amendment to AEC regulations, licensed fuel reprocessing plants are limited in liquid waste inventory to that processed in the prior five years. The liquid wastes must be converted to an approved solid form as necessary to comply with this limit, and be sent within another five years to a Federal Repository for long-term (that is, indefinite) storage. Technology to provide a basis for compliance with these regulations has been provided by AEC development programs, including full-scale demonstration of the pot, radiant spray, and phosphate glass processes in the Waste Solidification Engineering Prototype pilot plant at Pacific Northwest Laboratories. (See "Status of the Waste Solidification Demonstration Program," McElroy, Blasewitz, and Schneider, Nucl. Technol., Vol. 12, No. 1, pp. 69-82, Sept. 1971.)

The Nuclear Fuel Services Facility, West Valley, New York, is the only licensed fuel reprocessing plant currently in operation. To date approximately 525,000 gallons of high-level radioactive waste have been accumulated at NFS, and these neutralized liquid waste solutions are contained in underground storage tanks. The Midwest Fuel Recovery Plant, Morris, Illinois, scheduled to begin operation about mid-1972, will convert high-level radioactive waste to solid form for interim storage on site, pending the availability of a Federal Repository for such wastes. The Barnwell Nuclear Fuel Plant, Barnwell, South Carolina, is scheduled to begin operations in 1974. It will store high-level radioactive waste as nonboiling acidic solutions for an interim period prior to conversion of such wastes to a solid form for transfer to a Federal Repository.

Commercial land burial facilities are authorized to bury any waste other than high-level waste generated by fuel reprocessing plants. One of the major concerns in authorizing burial of radioactive wastes has been the possibility of environmental contamination. In this regard, careful review has been made of the geological and hydrological aspects of each of the burial sites to determine whether radioactive material would migrate from the burial site. Inspection of burial sites has indicated that there have been no significant problems associated with the burial of wastes. Results of environmental surveys, conducted by licensees at their burial sites, indicate that there has been no migration of radioactive material from the burial sites.

(2) Description of Available Data

Having outlined the principles on which control of radioactive wastes are based, it is appropriate to discuss the information that has been assembled. The following paragraphs describe the kinds of data available and indicate a few limitations on completeness and usefulness.

Some definition of terms was provided in the earlier discussion of low-, intermediate-, and high-level radioactivity. The significance of transuranium content was also discussed, since the categorization of solid waste packages according to "high" or "low" level of penetrating radiation may be completely inadequate as an indication of potential internal hazard. While a division of solid wastes into transuranic and nontransuranic classes is philosophically simple and may require important differences in storage techniques, it is technically and administratively difficult. Where solid wastes are transmitted to another site for burial or long-term storage, there may be uncertainty on the receiver's side that the shipper has properly classified each package. The receiver may, therefore, feel it necessary to open and inspect all packages, an operation of considerable cost and potential hazard.

Another definitional problem posed by any attempts to tabulate quantities of wastes is possible confusion between generation and disposition, which could lead to either double counting or noncounting. The problem comes partly from the fact that some sites "dispose of" wastes by shipping them to other sites where they are buried and hence in a sense "disposed of" again. (Buried wastes are not really "disposed of" in the sense of sewage plant effluents, since they are physically retrievable even though retrieval may never be planned or necessary.) Equally significant is the rehandling of liquid wastes during or after interim storage. Several AEC sites that have large inventories of tanked liquid wastes rehandle millions of gallons each year as a part of volume reduction and waste solidification programs. These quantities may greatly exceed the volumes of new waste generated.

Another category of limitations on the availability of data stems from the decentralized operational mode of AEC. General policies and programmatic objectives are established at Headquarters, with due regard for inputs from the Executive and Legislative Branches. But the implementation is delegated to field management which in turn administers the programs through contractors. In consequence, routine operational data on activities such as waste disposal are not transmitted to Headquarters. Collection of such data from the sites would require considerable effort and take several months.

On the other hand, it is recognized that there are advantages to the maintenance of centralized documentation of the geographical location of radioactive waste storage facilities and of the quantities and types of wastes stored in each. It is, therefore, contemplated that such a system of records be set up and, in fact, initial contacts have been made at some of the sites and data collection is underway. A year or more may elapse before this effort is complete.

Another source of difficulty in assembling the data is the lack of a single suitable unit of measurement for consolidation of waste quantities. While gallons or cubic feet are convenient units, and are used in the appended tables, they have little meaning for consideration of environmental impact. (They do indicate real estate requirements and offer some handle on costs, of course.) Tabulation of curies or megacuries might appear more sophisticated, but is not suggested here because a large fraction of the curie content of solid waste is composed of relatively short-lived fission products and induced activity and hence changes rapidly. For a particular storage site and a particular assumed accident situation, curie content—weighted by air, water or body burden index values for the major radionuclides present—is a useful parameter, but summation of such weighted values among sites is of questionable validity. Since normal conditions at a burial site involve zero release, volume consumed is the major parameter affecting duration of operations.

The last complication to be cited here is the need to avoid disclosure of information considered proprietary by the licensees. Since many of the firms involved in the generation, packaging, transport, and storage of the radioactive wastes are young and competition for business is keen, the publication of cubic feet buried per year or gallons stored per ton of fuel processed should be avoided. These proprietary aspects are protected by aggregating data or projections for three or more licensees; this still allows qualitative indications to be tabulated for each licensee, which provides at least some geographical interpretation to be made by or for EPA. (The alternative of tabulating actual or estimated quantities but concealing the geographical location would seem less helpful to EPA.)

Table A-12-22 shows the current practices at AEC sites on a qualitative basis for solid waste and low-, intermediate-, and high-level liquids, and indicates whether the solid wastes contain transuranics. The footnotes to this table on the next page indicate how the wastes are handled.

Table A-12-23 shows the available quantity data on the AEC sites with respect to present handling of high-level liquids and burial or shipment of solids. Five- and ten-year projections are presented for high-level liquids.

Table A-12-22

Qualitative Indices* to Types of Waste Handled at AEC Sites

Site	Liquid Wastes			Solid Wastes	
	Low Level	Intermediate Level	High Level	Contains Transuranics	No Transuranics
HAN	(1)	(2)	(3)	(4)	(6)
SR	(1)	(2)	(3)	(4)	(6)
NRTS	(1)	(2)	(10)	(4)	(6)
LASL	(1)	(2)	None	(4)	(6)
ORNL	(1)	(2, 9)	None	(4)	(6)
FMPC	(1)	None	None	None	(11)
Y-12	(1)	None	None	None	(6)
RF	(1)	(2)	None	(5)	(7)
SAN	(1)	None	None	(4)	(6)
PANT	(1)	None	None	(4)	(6)
NTS	(1)	None	None	(6)	(6)
K-25	(1)	None	None	None	(6)
PAD	(1)	None	None	None	(6)
PORT	(1)	None	None	None	(6)
MOUND	(1)	(2)	None	(8)	(8)
BNL	(1)	(2)	None	None	(8)
ANL	(1)	(2)	None	(8)	(8)
BMI-C	(1)	(2)	None	None	(8)
LRL-B	(1)	None	None	None	(8)
LRL-L	(1)	None	None	None	(8)
SNPO	(1)	None	None	None	(8)
BET	(1)	None	None	None	(8)
NB	(1)	None	None	None	(8)
AMES	(1)	None	None	None	(6, 8)
PIN	(1)	None	None	None	(7)
LOV	(1)	None	None	(8)	(8)

* See next page for key to index numbers and page A-12(71) for identification of sites.

Key to Indices of Table A-12-22

(1) Monitored; treated if necessary; after treatment, effluent released and residue handled as solid waste.

(2) Treated by evaporation, precipitation, ion exchange, decay storage, etc.; after treatment, effluent released at or below limits and residue handled as solid waste or high-level "liquid."

(3) Concentrated for interim and long-term storage; overheads treated as intermediate- or low-level waste.

(4) Buried retrievably on site.

(5) Shipped to approved site for retrievable burial.

(6) Buried on site.

(7) Shipped to AEC site for burial.

(8) Shipped to commercial burial ground.

(9) Some ILW has been disposed of by hydrofracturing.

(10) Treated by fluidized bed calcination and stored as dry, granular solid.

(11) Placed in raffinate pits with sludges from low-level liquid treatment.

Table A-12-23

Quantities of Wastes Handled per Year at AEC Sites

Site	High-Level Liquids (million gallons)			Solid Wastes(2)
	Present	Estimated 1977	Estimated 1982	(thousand cu. ft.) Present(3)
HAN(1)	8.0	0.6	0.1	150
SR(1)	5.0	5.0	5.0(5)	370
NRTS(1)	0.6	0.7	0.7	400
LASL	None	None	None	190
ORNL	None	None	None	160
FMPC	None	None	None	30
Y-12	None	None	None	30
RF	None	None	None	220
SAN	None	None	None	<10
PANT	None	None	None	-
NTS	None	None	None	10-20
K-25	None	None	None	<10
PAD	None	None	None	10-20
PORT	None	None	None	<10
MOUND	None	None	None	100
BNL	None	None	None	<10
ANL	None	None	None	30-40
BMI-C	None	None	None	<10
LRL-B	None	None	None	<10
LRL-L	None	None	None	20-30
SNPO	None	None	None	10-20
BET	None	None	None	20-30
NB	None	None	None	<10
AMES	None	None	None	<10
PIN	None	None	None	<10
LOV	None	None	None	10-20
Total	14(6)	6	6(5)	1700(4)

* See next page for notes and page A-12(71) for identification of sites.

Key to Indices of Table A-12-23

(1) Liquid waste volume figures are primarily based on the rehandling of stored inventories since these mask the smaller volumes from current operations and some of the latter are classified.

(2) For this column, "handled" means buried or shipped as indicated in Table A-12-22; excludes solids produced by concentration of high-level liquids.

(3) Based on data for 1969, 1970, or 1971.

(4) Total burials at AEC sites; excludes quantities shipped to licensed commercial burial grounds.

(5) Assumes continued operation of production facilities.

(6) Current inventories total about 86 million gallons of liquids, sludges, and wet salt cake.

Identification of Sites for Tables A-12-22 and -23

Site	Designation	Location	Contractors
AMES	Ames Laboratory	Ames, Iowa	Iowa State Univ.
ANL	Argonne National Lab.	Argonne, Ill.	Univ. of Chicago
BET	Bettis Atomic Rower Lab	Pittsburgh, Pa.	Westinghouse
BMI-C	Battelle Memorial Inst.	Columbus, O.	Battelle Mem. Inst.
BNL	Brookhaven Nat. Lab.	Upton, N. Y.	Asso. Universities
FMPC	Feed Materials Production Center	Fernald, O.	National Lead Co. of Ohio
HAN	Hanford Facilities	Richland, Wash.	Several(1)
K-25	Oak Ridge Gaseous Diffusion Plant	Oak Ridge, Tenn.	Union Carbide
LASL	Los Alamos Scientific Laboratory	Los Alamos, N. M.	Univ. of Calif.
LOV	Lovelace Foundation	Albuquerque,N.M.	Lovelace Found.
LRL-B	Lawrence Radiation Lab, Berkeley	Berkeley, Calif.	Univ. of Calif.
LRL-L	Lawrence Radiation Lab, Livermore	Livermore,Calif.	Univ. of Calif.
MOUND	Mound Laboratory	Miamisburg, O.	Monsanto Res.
N. B.	New Brunswick Lab	New Brunswick,N.J.	(AEC)
NRTS	National Reactor Testing	Idao Falls, Idaho	Several(2)
NTS	Nevada Test Site	Mercury, Nev.	Reynolds Elec. & Eng. Co.
ORNL	Oak Ridge Nat. Lab.	Oak Ridge,Tenn.	Union Carbide
PAD	Paducah Gaseous Diffusion Plant	Paducah, Ky.	Union Carbide
RF	Rocky Flats Plant	Rocky Flats, Col.	Dow Chemical
SAN	Sandia Laboratories	Albuquerque,N.M.	Sandia Corp.
SNPO	Space Nuclear Propulsion	Jackass Flats,Nev.	Westinghouse

Site	Designation	Location	Contractors
SR	Savannah River Facil.	Aiken, S.C.	E.I. du Pont de Nemours & Co.
Y-12	Y-12 Plant	Oak Ridge, Tenn.	Union Carbide

(1) Atlantic Richfield Hanford Company; Douglas United Nuclear; WADCO (subsidiary of Westinghouse); Battelle-Northwest (Division of Battelle Memorial Institute).

(2) Argonne National Laboratory; General Electric Company; Idaho Nuclear Corporation; Westinghouse.

6. RADIOACTIVE WASTE TREATMENT - CURRENT AND FUTURE

Standard chemical waste treatment systems are used to collect, concentrate and immobilize radioactive waste. A brief description of the currently used equipment and systems is given in the following paragraphs followed by a brief discussion of new and improved systems which will be in use in the near future.

(1) Current Effluent Treatment Systems

1. Gases —Gaseous effluents are generally air which contains either or both radioactive gases and radioactive particulates. Gaseous effluent streams with radioactive particulates are passed through high efficiency filters capable of a 99.97 percent removal of particles down to 0.3 micron in size. An alternate to the high efficiency filters for very large installations is a sand filter bed which has a comparable efficiency. Gaseous effluents with a radioactive gas component are treated in accordance with the radiotoxicity of the gas. In general, radon gas of low toxicity from mining and milling operations is diluted and released; short half-life xenon and krypton radionuclides from reactor operations are delayed and decayed before release, and the more toxic radioiodines

released during fuel reprocessing are removed from other gaseous effluents by means of charcoal absorption, chemical scrubbing and adsorption in silver reactors.

2. Liquids — Most liquid effluents are water with small quantities of soluble or insoluble radioactive material. These low-level radioactive waste effluents undergo a combination of settling, precipitation, filtration, evaporation, and demineralization operations as appropriate to remove the radioactive material before the water is released.

3. Solids — Solid radioactive wastes are generally contaminated solid materials such as ion exchange resins used to remove radioactivity from liquid streams, or high efficiency filters used to collect particulates in gaseous effluents, or rubber gloves, kleenex, and other equipment used in particular operations, or solidified radioactive waste concentrates from liquid waste treatment systems, etc. These low-level waste materials are usually shipped to an authorized waste burial facility (see Table A-12-19) for final disposal.

The shipment of radioactive material is in authorized, well-engineered packages which have been designed to meet rigorous safety requirements. If the material shipped is more than a very small quantity (millicuries for the more radiotoxic materials), the package must, in addition to being capable of withstanding the normal conditions of transport, be capable of meeting a severe hypothetical accident represented by a 30-foot drop of the package onto an unyielding surface, followed by a 40-inch drop onto a 6-inch diameter steel cylinder, followed by a 30-minute exposure to a 1475° fire, then finally total immersion for 24 hours under water. At the completion of this series of tests, the package must not release more than a very small quantity of its radioactive contents or it is not authorized.

(2) Future Waste Treatment Systems

Most of the current waste treatment systems are performing adequately enough to meet the existing license requirements. Nevertheless, these systems will have to be refined and supplemented in the near future in order to comply with the U.S. AEC announced regulatory policy of maintaining radioactive releases to the environment at the lowest practicable limits. Most of the upgrading of waste treatment will be necessitated by a further restriction on gaseous and liquid releases from the power reactors and the fuel reprocessing plants. New power reactor designs are tending more and more to the so-called "zero" or "mini" release systems which provide for removal or additional decay of the several gaseous xenon and krypton radionuclides and a more complete internal plant recycle of water. Similarly, the reprocessing plants will be faced with the necessity of designing and providing systems for removing the noble gas Kr-85 and reducing low-level liquid discharges to an absolute minimum. Current reprocessing designs provide for an in-plant recycle of water and, therefore, have no liquid discharge.

The reprocessing plants have, in addition to some upgrading of low-level radwaste treatment systems, a much more complex problem to solve; namely, that of converting the stored, high-level fission product and actinide liquid waste, which are the result of reprocessing, to an acceptably immobile solid waste form which will permit its ultimate disposal. Another area for research and development, but to a much lesser degree than that required for high-level wastes from reprocessing, is to find an economically feasible system for containing tritium, an existing effluent from both power reactors and fuel reprocessing plants. When the new gaseous and liquid treatment systems are installed and operable, the nuclear industry will have confined its waste effluents except for tritium which does not pose an immediate health and safety problem to the public. The proposed new types of waste collection systems are as follows.

1. Gases—In the case of boiling water reactor, the proposed systems for radiogases are as follows:

   - The use of pressurized storage to permit an extended decay period prior to release,
   - After minimizing the gaseous volume by catalytic recombination and dew point reduction, the ambient temperature absorption of the noble gas in charcoal beds to extend their decay period before release, and
   - A cryogenic distillation of the off-gas to recover the xenon and krypton components for long-term storage.

2. Liquids—Upgrading of liquid waste treatment systems will primarily be by the addition of filtration evaporation and ion exchange systems to permit a more complete internal plant recycle of water.

3. Solids—It may be necessary in the near future to isolate contaminated wastes to a greater degree than previously necessary. In this event, long-term storage

facilities will have to be provided for these materials pending their ultimate disposal.

The fuel reprocessing plants can use similar systems to those at nuclear power facilities to reduce their gaseous and liquid effluents. The high-level waste treatment considerations, however, are very different. In this regard, the U.S. AEC has for some time at its Brookhaven, Oak Ridge and Hanford facilities been developing techniques for concentrating and solidifying the high-level radioactive wastes from reprocessing into an acceptable form for long-term storage. Recently the work on the performance of three waste solidification techniques(9, 10, 11) was completed at Batelle Northwest in Richland, Washington. These techniques are phosphate glass solidification, spray solidification, and pot solidification.

The phosphate glass process, originally tested by Brookhaven National Laboratory, consists of an evaporative denitration of the high-level waste after the addition of phosphoric acid, sodium hydroxide, and ferric nitrate. The bottoms discharge of the denitrator is melted and collected in a pot for final storage. The overheads from denitration are condensed and re-evaporated with the bottom, recycled to the denitrator feed tank, and the overheads fractionated for nitric acid recovery. The aqueous effluent was decontaminated by a factor of 10^7 to 10^8 for the non-volatiles, and by 10^5 to 10^6 for the radio-ruthenium. Storage of the phosphate glass product was adequate; no increase in pressure after the pot cap was welded in place.

The spray solidification process utilized a spray calciner to solidify the incoming high-level waste liquor followed by a fusing of the solids directly in the storage container using a sodium borosilicate frit as a melt additive. The off-gas from the calciner is condensed and re-evaporated, and the overheads are fractionated for HNO_3 acid recovery. The bottoms of the evaporator are recycled to the calciner feed tank. The aqueous effluent was decontaminated by a factor of 10^9 for non-volatiles and 10^5 or 10^6 for radio-ruthenium. The waste containers were capped and welded and showed no pressure buildup.

The pot solidification process, originally tested at Oak Ridge National Laboratory, is a direct solidification in the storage container used for ultimate disposal. The use of auxiliary evaporator, fractionator, and scrubber equipment provided a 10^9 decontamination factor for the liquid effluent and greater than 10^3 for radio-ruthenium. The sealed containers are still undergoing tests at the Solids Storage Engineering Test Facility at Hanford.

One of these basic techniques will undoubtedly be utilized in the near future by both NFS and Allied-Gulf in order to comply with the recent AEC regulation making it mandatory to convert stored high-level waste liquids to a form acceptable for ultimate disposal. GE has already included spray calcining of the high-level waste in its design of the Midwest Fuel Recovery Plant.

Among the remaining problems associated with radioactive waste materials are the location and type of Federal Repository required for high-level solidified wastes, the methods of handling and ultimately disposing of alpha wastes, and finally, but of much less immediacy, the collection and retention of tritium.

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(10) Spray Solidification Performance during Final Radioactive Test in WSEP, W. R. Bond, et al, June 1971 (BNWL 1583).

(11) Pot Solidification Performance during Final Radioactive Tests in WSEP, J. L. McElroy, et al, January 1972 (BNWL 1628).

(12) Radioactive Waste Handling Information, Letter from Mr. Alex F. Perge, Assistant Director for Development and Transportation, Division of Waste Management and Transportation, Atomic Energy Commission, February 14, 1972.

APPENDIX A-13

WASTE MANAGEMENT

DEPARTMENT OF DEFENSE

1. ECONOMIC STATISTICS

The Department of Defense (DoD) has the following resources:

- An annual budget of $70 - $80 billion
- Real property valued at $46 billion

  (Total government real property value - $102 billion)
- Personal property valued at $143 billion

  (Total government real property value - $244 billion)
- Forty-three percent of the 3 million federal employees
- Military strength of approximately 3,000,000 (1971)
- Several hundred major bases
- Operation of major production, housing, hospital, harbors, airfield, maintenance, and support facilities at home and overseas.

Much of the industrial economy is influenced by DoD decisions and resultant requirements for goods and services. Goods range from aircraft carriers to paper clips. The feeding and housing of the military forces involves not only those in military service, but their dependents as well. Every conceivable human activity is likely to be represented within its forces.

The magnitude and scope of its operations insure that the Defense Department is actively involved in all aspects of waste creation, control, and disposition. Because it operates through a well defined command structure, it can readily establish controls over its disposal problems and, to the extent that funds are available, implement advanced disposal procedures. This capability, to readily apply control measures as needed, may provide an opportunity to test disposal control procedures within the Defense environment and establish their feasibility and costs prior to advocation of their use by the country at large.

2. WASTE MANAGEMENT

The Department of Defense, through its component departments (Army, Navy, and Air Force), has a long history of effective waste disposal practices. Safeguarding the health of the military establishment has been a vital mission since the initial forces were gathered to win freedom for the country. Practices developed within the military medical departments have been precursors for similar sanitary advances within the country as a whole.

The manufacture and use of weapons has required the continuous evaluation of hazards and the development of regulations for their safe control. Each new weapon or munition development has required the development of a support system which included its final disposition. Such support systems frequently prescribe each stop in the acquisition, storage, use, maintenance, and disposal of such items as procurement specifications, labeling, packaging, and inspection procedures, as well as precise direction for its final destruction.

(1) Organization for Control

In addition to the procedures which have been followed for years, DoD has recently established a monitoring and control system to ensure that all practical steps are taken to reduce the release of pollutants to the environment. At the DoD level, the Assistant Secretary (Health and Environment) ensures that all directives are adequately prepared and fully implemented. Each service provides an office at departmental level to monitor and direct environmental activities. Such directions include monitoring programming and budget actions to ensure that funds are directed toward the priority programs. The actions and programs within all echelons of the Defense Department are also monitored by the Environmental Protection Agency (EPA), by their review of environmental impact statements which must accompany all new program submissions. Fundamentally, however, control is exercised through normal command channels. Command priority is given to ensuring that all measures which can be taken to reduce hazardous wastes are taken.

The actual waste disposal practices within the service can be grouped functionally into those concerned with post, base, or station operations; those related to production operations; those concerned with supply and maintenance operations; and those related to weapon systems.

(2) Base-Post-Station Operations

In most respects, waste disposal at the major permanent operating facilities are comparable to those of a modern city of the same approximate size which has an active, aggressive waste management program. A study recently completed by the U.S. Air Force (USAF) at 98 major installations (Reference 1) shows that 3.5 pounds per day of household wastes are generated. This compares closely with the figure of 3.0 pounds per day established by the 1968 National Survey of Civilian Communities. This study also provides data on pathological wastes from hospitals, liquid industrial wastes, and pesticides and herbicides in storage (Tables A-13-1 and A-13-2). This latter category includes material whose use has been restricted, as well as materials whose containers have deteriorated and which are potential hazards while in storage.

Table A-13-1
Typical Base Data

Wastes	No. Bases Reporting	Total Tons/Mo.	Ave. Lbs/ Pers/Day
Base solid wastes	90	64,858	5.11
Family housing solid wastes	90	21,853	3.94
Wastes	**No. Bases Reporting**	**Total Ft^3/Mo.**	**Ave. Lbs/Yd^3**
Base solid wastes	98	20,893,463	172
Family housing solid wastes	98	6,648,239	188

The pathological wastes generated on 77 bases average 42,371 pounds per week, or 5.63 pounds per bed per week. Classified wastes, as reported from 95 bases, were 805 tons per month. Kelly Air Force Base averages 353 tons per month. The average base (not including Kelly Air Force Base) produces 327 pounds per day of classified waste (classified documents).

The following data indicates the total volume of industrial type wastes which are produced monthly. The data is for all reporting bases.

Table A-13-2
Liquid Industrial Wastes

Waste Material	Bases Reporting	Average Gal/ Mo. (All Bases)
Engine oil	86	115,301
Hydraulic fluid	82	12,209
Industrial fluids and petrochemicals	87	187,736
Contaminated fuel	91	241,859
Emergency fuel destruction	97	9,040
Other wastes	11	93,889
Fire training fuel	98	148,671
TOTAL		808,705

This data indicates that each base will produce between 8,000 and 9,000 gallons of petroleum product wastes monthly.

The data provided above represents a substantial portion of the U.S. Air Force. The per capita data shown are probably comparable to data which would be obtained in similar surveys in other services.

Typically, the base or post engineer is responsibile for disposal operations at each facility. He is assisted, as needed, by sanitation engineers who are members of the U.S. Army Environmental Hygiene Agency, or a similar unit whose operations are supervised by the Surgeon General of each service. These specialists continuously inspect all operations to insure compliance with regulations and to develop solutions to difficult disposal problems.

The disposal of household wastes on military bases is comparable to civilian practices. On permanent bases, all sewage is given a minimum of secondary treatment. In most cases, additional treatment is given. The disposal of solid collectible wastes follows conventional practices; over 95 percent is placed on landfill either by contractors or by service employees. Some incineration takes place and increased funding will enable more modern incinerators to be built. Pathological wastes are incinerated to reduce them to disposable ash.

Pharmaceuticals are primarily disposed of by incineration, although some are still buried in carefully supervised landfills.

Service disposal facilities may be augmented by contract with civilian communities or agencies. Not infrequently, service sewage or other disposal facilities may be used by civilian communities. Extensive programs are underway in all services to modernize their disposal facilities to fully satisfy environmental standards.

The USAF report provides a detailed picture of current practices, as well as recommendations for additional progress towards better disposal practices.

(3) Production Processes

The census data for 1967 credits the Defense Department with over 4 billion dollars in manufacturing billings; about one-fourth in research and development, one-fourth in ordnance, one-fourth in ship building, and the balance scattered among such activities as aircraft, communications, and miscellaneous chemical products. This data may understate, somewhat, the extensive operations of the U.S. Army Ammunition plants which are government-owned, but contractor-operated.

The munition manufacturing plants were built in World War II because of the reluctance of civilian industry to invert in facilities which are frequently inactive. Currently, they are operating in support of Southeast Asia requirements. They are the largest group of government production facilities and produce propellants, explosives, and assemble munitions of many types.

The Naval Shipyards are also part of the historic arsenal and shipyard system which has provided logistic support to the combat elements since the country was founded. Although new shipping and ship repairs may be contracted to private yards, extensive repair and refitting operations are conducted within government-operated facilities.

The production operations in these facilities, with the exception of the munitions plants, generate wastes comparable to those found in the metal assembly industries. Typical wastes include solvents, detergents, cutting oils, boiler blowdown residues, oily wastes, and paints and lacquers. Controls are exercised over these wastes to insure compliance with both state and federal requirements.

(4) Maintenance Operations

The military services have an extensive inventory of hardware which requires continual maintenance. Such activities scale up from simple motor pool maintenance operations to such complex facilities as small carriers used exclusively for maintenance operations. Minor maintenance facilities are established in all permanent posts and bases, as well as overseas to support local needs.

More extensive facilities have been developed to enable complete overhaul or rebuilding of major items of equipments such as trucks, tanks, and aircraft. These facilities are comparable to a manufacturing plant in the scope of operations and in the wastes generated.

(5) Supply Operations

The support of the defense establishment throughout the world requires an extensive system of supply depots and the means to move supplies. Extensive storage, classification, packing, and movement capabilities are required. Buildings vary from simple sheds to fully automated warehouses comparable to those of Sears Roebuck or General Motors. Means of movement vary from hand trucks to massive C-5A aircraft. Since the supply system deals with all items (clothing, food, medicines, munitions, weapons, etc.),the storage problems which arise from deteriorating or worn-out material cover a wide spectrum.

Disposal is part of the responsibilities of the supply system. This operation gathers together worn-out or excess equipment (supplies for sale to the highest approved bidder or for safe disposal in government disposal facilities). Close control over all items in the supply system enables the Services to collect, for recycling operations, items such as mercury switches, batteries, or lights. Service disposal operations may provide a useful model for collection and recycling operations in the civilian community.

(6) Weapon Systems

Weapons used in the services range from individual items, such as pistols and knives, to exotic ship aircraft, missile, and ground systems which employ a variety of exotic warheads.

Before any weapon system is fielded, plans for its continuous support, maintenance, and safe disposition have been made. All potential hazards have been investigated and steps taken to negate or control such hazards. Much as a fire department continuously trains to overcome civilian accidents, skilled military personnel train to immediately remedy any failure in systems safety. Explosive Ordnance Disposal personnel are on call at all times to take over in the event of accidents. Nuclear, chemical, and other exotic weapons systems have expert hazards control personnel available, too.

This brief review of the various functional areas within the Department of Defense that generate, and are concerned with, waste disposal provides an overview of the magnitude and diversity of waste disposal within the Services. The following paragraphs discuss the type of hazardous wastes which may be produced in each of these functional areas.

3. CURRENT DISPOSAL OPERATIONS

(1) Chemical Munition Production

The clean-up and decontamination of munitions, facilities, and land areas used in the manufacture of chemical agents and munitions pose a special problem. Three major projects concerned with these wastes are now underway.

The first involves the demilitarization of excess and unserviceable stocks of mustard and nerve gas munitions and agents at Rocky Mountain Arsenal. The demilitarization process will produce solid toxic residues which will require further disposition. The disposal of wastes from the production of these agents in past years must also be considered. These wastes are now contained in a sizeable lake. The pollutants which will be generated in the munitions disposal phase include sodium fluoride, chloride, sulfide, and sulfate and sodium salts from the reaction of sodium hydroxide and GB. The materials in the lake include arsenicals from the manufacture of Lewisite in World War II. There are about 130 million gallons of 7 to 8 percent dissolved solid waste in the lake, while the program for the disposal of munitions may develop an additional 25 million gallons of waste.

Reduction of these wastes to residue solids will be costly. Special demilitarization process equipment is being assembled. This equipment will be transportable so that it may be moved throughout the country to dispose of other munition stocks where they are now stored.

The cleanup of the lake will be expensive if not prohibitive in cost. Present plans call for evaporation of the lake by natural processes augmented by spray drying. Once dry the lake will still contain toxic salts. To fully explore the extent of soil contamination may involve the taking of thousands of core samples and their subsequent chemical analyses. An estimated 12 million cubic feet of soil may have to be removed and disposed of elsewhere.

This particular project points up the expense involved if existing civilian lagoons or sludge piles are to be cleaned up. As air and water pollution standards are enforced and more contaminants are removed from air and water, the problem of handling toxic sludge will become greater.

At another location, the manufacture of incendiaries over many years has resulted in a significant accumulation of "phossy water" containing phosphorus slag, elemental phosphorus and oxides of phosphorus. Over 200 million gallons of water will require treatment.

A third major problem is to clean up sludge deposits from streams which have accumulated over the years as residues from the manufacture of pyrotechnics and incendiaries. These sludges contain dyes, sulfur, magnesium, aluminum and organic wastes.

These three disposal projects may be the precursors of similar clean-up operations which may be demanded elsewhere. The results of these clean-up attempts may be helpful in illuminating the magnitude of ultimate disposal operations and costs, if all such contaminants are to be safely removed.

(2) Biological Material

Recent presidential decisions, to substantially reduce biological operations,have required that all stockpiles be demilitarized. Such operations are now underway at locations having such stocks. The basic treatment involves sterilization and subsequent incineration to a harmless residue. These operations will be performed by the military services under the continued guidance of state and federal authorities.

(3) Nuclear Material

In general,there are three different categories of nuclear materials and wastes; those related to weapons, those associated with sources and radioisotopes, and those related to nuclear reactors. Because of the classification associated with nuclear weapons, this area will not be discussed. It will be treated in general fashion in the discussion of Atomic Energy Commission (AEC) waste disposal activities.

The use of radioisotopes and sources within the military structure is comparable to their use and control through the civilian sector. The Atomic Energy Commission establishes the basic rules, licenses the holders, and inspects to ensure that all provisions of their regulations are enforced. The military services have a substantial number of officers who are specially trained in the use and care of nuclear materials. The safeguards imposed by the AEC are further elaborated by service regulations and guides.

All services have a guidance committee to monitor and approve all actions with respect to reactors. The U.S. Army Reactor Health and Safety Committee includes one representative from the Surgeon General's office, two from the Corps of Engineers, one from the Army Materiel Command, one from the Transportation Corps, and one from the Army Reactor Group (an engineer unit at Fort Belvoir). Under AEC guidance these groups insure that all procedures relating to operation and waste disposal are carried out. AEC checks on this committee by annual inspections of all operations involving nuclear materials.

Nuclear wastes which accumulate at any post, base, or station are the responsibility of the licensed holder to safeguard and to release to approved disposal contractors. The latter, when notified, pick up the wastes and transport them to final national disposal sites.

Each of the services operates one or more nuclear reactor, with 96 nuclear powered submarines and ships in the U. S. Navy nuclear ship program. Enclosed as Attachment A-13-I is a description and the data on the U. S. Naval program for the disposal of radioactive wastes and their environmental monitoring procedures.

(4) Excess or Unsafe Munitions

In prior years, munitions which were unsafe or in excess of the need, were disposed of in the most economical manner, generally by burning, detonation, or dumping at sea. Then, as now, every effort was made to recover the items of value, if it could be done safely. When practical, the explosive was recovered and the metal casings salvaged for eventual meltdown and reuse. Many thousands of tons of incendiary and toxic munitions were burned under carefully controlled conditions.

Present regulations sharply restrict disposal methods. Limitations on atmospheric release which preclude open-pit burning and restrictions on movement of toxic munitions, have led to the development of a transportable incineration system to accomplish the in-place clean-up of toxic munitions at their present storage sites. Ocean dumping, formerly used as an ultimate disposal means, has been suspended, while other disposal alternatives are evaluated.

The magnitude of the munition disposal operation can be measured by the fact that over 100,000 tons have been ocean dumped since 1964. The current estimate is that approximately 80,000 tons of Navy ammunition now require disposal, and more will be added to this amount as activity in Southeast Asia ends. Army munitions disposal requirements will be at least as large.

Present plans call for extensive use of munition demilitarization, i.e., the recycling of most or all of the explosives and metal parts. Such operations will be keyed to ammunition renovation programs continuously operated at major storage areas.

(5) Packaged Hazardous Materials

The services' depots contain most products known to man. Among these products are chemicals, herbicides, pesticides, industrial gases, and similar products used in housekeeping, maintenance, production and renovation activities. Such chemicals can be hazardous if not properly handled, stored, or packaged or, if they remain in storage for long periods of time, deterioration of the packages or contents may create hazardous or potentially hazardous effects.

Although safety guides, handling instructions, inspection procedures, and stock rotation and disposal techniques eliminate much of the potential danger, occasionally hazardous conditions can arise. Recently, cans containing wood treatment material arsenals began to leak and were sold as a lot to a small plant which treated wood. Because the lot-size was in excess of his needs, the buyer sold the excess stock. The next purchaser who wanted only the cans, poured out the contents and, in so doing, poisoned several local wells. Because events do occur, procedures governing the disposal of potentially hazardous materials are continuously reviewed and tightened.

Within the Army, the U.S. Army Environmental Hygiene Agency (AEHA) acts as advisor to installations who have special disposal needs. The other services have similar organizations who make on-site inspections and design special disposal methods in unique situations. Recently, the AEHA proposed that all material procurement specifications prescribe safe disposal practices for all packaged products. Such disposal instructions would augment present labelling requirements.

The military services have long recognized that extreme care must be taken to protect people and property from the hazards. Safety programs in munitions production and handling have been directed and monitored by the Armed Services Explosives Safety Board. The U.S. Army Environmental Hygiene Agency, and its counter-parts in the other services, supervise all aspects of sanitary, industrial, and environmental safety.

The prevention of hazardous conditions is emphasized in the design, construction and use of facilities and equipment. The care taken,in such matters,is illustrated by the ability of the services to produce toxics in substantial quantities while fully containing the toxic products and by-products. While perfection has not been attained, many of the service design practices may have useful application in history.

The specific effects of hazardous munitions are well defined with voluminous effects-data available. The persistency of such effects is also known (e.g., mustard gas can remain in the soil for years and still be hazardous). The effects of more common wastes, such as oils and surfactants, is much less well known. The services have not made specific efforts to define effects on civilian commodities. The military laboratories which have developed such precise data on military weapons effects over various geographic areas have the skills to explore the effects of the more mundane hazards, if so directed. Use of these skills to assist in establishing hazard potentials of industrial toxics would appear desirable.

Currently all services have extensive programs to improve disposal systems so as to fully meet the stringent requirements of current legislation. This historic concern for personal and property safety has been broadened to encompass the total environment.

4. HAZARDOUS WASTES

Since DoD activities are comparable in many respects to the civilian community, many of the same hazardous materials are procured, stored and used. While the manufacturing facilities are not nearly as extensive, the munition and agent production facilities of the services are extensive.

Typical air and water toxic pollutants involved in conventional munition production include

Air	Water
Acetic Acid	Acetic Acid
Acetic Anhydizide	Hexamine
Ammonia	Ammonia
Butyl Alcohol	Sodium Nitrate
Cyclohexanone	Sodium Sulfate
Formic Acid	Phenols
Iso Butyl Acetate	Iso Butyl Acetate
Methylacetate	Ammonium Nitrate
Methy Ethylacetone	Nitric Acid
Nitric Acid	Oils
Oxides of Nitrogen	Explosives
Toluene	Red Water
Other Organics	Sulfuric Acid.

The production of toxic agents results in wastes such as those previously noted. Other hazardous wastes include typical compounds involved in the following operations.

- Maintenance

  Cleaning Solvents
  Paints and lacquers
  Plating wastes
  Oily wastes
  Surfactants

- Supply

  Toxic munitions
  Explosive munitions
  Propellants
  Oxidizing agents
  Flammable liquids
  Explosives
  Pyrotechnics
  Pesticides and herbicides
  Drugs and medicinals
  Corrosive liquids
  Nuclear weapon components
  Laboratory chemicals

- Weapon Systems Support

  Hydrazine
  Monomethylhydazine
  Borane
  Analines
  Hydrocarbon fuels
  Liquid oxygen
  Solid propellants
  Warheads - nuclear, non-nuclear
  Fluorine.

The disposal methods used within the DoD establishments are comparable, in all respects, with the best practices found in industry or municipalities. In some respects, their standards are more restrictive and their programs for reducing air and water pollution more comprehensive.

The most significant difference in waste disposal techniques between the DoD establishment and their civilian counterparts, is the degree of control which can be exercised over the disposal process. Implementation of desirable programs is limited only by available funds. Instruction as to what shall be done and by whom assures implementation when resources are made available. The salvage programs operated within the service provide a means to collect, selectively, items such as mercury containing products, which should be recycled rather than dumped. The controls which can be exercised over waste disposal efforts indicate that DoD may provide an ideal test area for "trying out" elements of any proposed national disposal system.

ATTACHMENT A-13-I

Report NT-71-1
February 1971

ENVIRONMENTAL MONITORING AND DISPOSAL OF RADIOACTIVE WASTES FROM U. S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES

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SYNOPSIS

This report summarizes data on disposal of radioactive wastes from U. S. Naval nuclear-powered ships and their support facilities and summarizes results of environmental monitoring performed to confirm adequacy of waste disposal limits and procedures. The total radioactivity discharged into all ports and harbors was 0.024 curie in 1970, less than one hundredth the total annual discharges of the early 1960's. Results of environmental surveys of harbor water and bottom sediment for gross radioactivity and for cobalt 60 show that (1) no increase in radioactivity has been detected in harbor water, (2) discharges of liquid wastes from U. S. Naval nuclear-powered ships have not caused a measurable increase in the general background radioactivity of the environment, and (3) low-level cobalt 60 radioactivity is detectable in localized areas of harbor bottom sediment around a few piers at operating bases and shipyards where maintenance and overhaul of Naval nuclear-powered ships have been conducted over a period of several years; these levels have decreased in recent years.

This report confirms that procedures used by the Navy to control discharges of radioactivity from U. S. Naval nuclear-powered ships and their support facilities are effective in protecting the health and safety of the general public.

The radioactivity in wastes discussed in this report originates in the pressurized water reactors of U. S. Naval nuclear-powered ships. As of the end of 1970, there were 92 nuclear-powered submarines and 4 nuclear-powered surface ships in operation. Construction, maintenance, overhaul and refueling of these nuclear propulsion plants involve nine shipyards, eleven tenders, and two submarine bases. This report first describes disposal of radioactive liquid wastes, then solid wastes. The final section discusses monitoring of the environment to determine the effects of radioactive discharges. This report brings up to date information in the Navy's 1959 report, reference 1.*

RADIOACTIVE LIQUID WASTE DISPOSAL

In the shipboard reactors, pressurized water circulating through the reactor core picks up the heat of nuclear reaction. Reactor cooling water circulates through a closed piping system to heat exchangers which transfer the heat to water in a secondary steam system isolated from the primary cooling water. The steam is then used as the source of power for the propulsion plant as well as for auxiliary machinery. Discharges of radioactivity from ships occur primarily when reactor coolant water expands as a result of being heated to operating temperature; this coolant passes through a purification system ion-exchange resin bed prior to discharge.

Liquid wastes discharged by support facilities result from operations such as draining shipboard reactor systems, decontaminating radioactively contaminated piping systems, and laundering anticontamination clothing worn by personnel. These facilities are equipped with processing systems to remove most of the radioactivity from liquid wastes prior to discharge into harbors.

The principal source of radioactivity in liquid wastes is from trace amounts of corrosion and wear products from reactor plant metal surfaces. Radionuclides with half-lives greater than one day in these corrosion and wear products include tungsten 187, chromium 51, hafnium 181, iron 59, iron 55, zirconium 95, tantalum 182, manganese 54, cobalt 58, and cobalt 60. The predominant and also longest lived of these is cobalt 60, which has a 5.3 year half-life; cobalt 60 also has the lowest concentration value for water listed by organizations which set radiological standards in references 2, 3 and 4 for these corrosion and wear radionuclides. Conservatively therefore, radioactive waste disposal is controlled by assuming that all the long-lived radioactivity is cobalt 60.

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* References are listed at end of report.

The total amounts of long-lived radioactivity discharged into harbors and seas within twelve miles from shore during the past five years are listed in Table 1, which updates information in references 5 through 9. Included are data from U. S. Naval nuclear-powered ships and from supporting shipyards, tenders and submarine bases. Locations listed in Table 1 include operating bases and home ports in the U. S. and overseas which have been visited by Naval nuclear-powered ships. The quantities of radioactivity listed in this table are reported as if the entire radioactivity consisted of cobalt 60, the predominant long-lived radionuclide.

Although this table shows both gallons and curies discharged, the curie data are the more important. In 1970 the gallons shown in Table 1 for most of these organizations are no more than many single U. S. homes discharge to their sewage systems each year.

The table shows that nearly all the radioactive discharges occur where shipyards are overhauling nuclear-powered ships. In 1970, for example, a total of 0.024 curie was discharged into all harbors, including those outside the U. S. Essentially all of this came from shipyards overhauling nuclear-powered ships. Less than one percent of the total was discharged into all other harbors entered by U. S. Naval nuclear-powered ships in 1970.

This total radioactivity discharged into harbors is less than the U. S. Public Health Service (USPHS) in reference 10 reports most individual electrical power generating nuclear reactors discharge each year. Evaluation by USPHS (applicable divisions of which were incorporated in Environmental Protection Agency late in 1970) of the small radioactive discharges from electrical power generating reactors shows that these discharges caused little or no increase in environmental radioactivity.

The 0.024 curie total from the Navy nuclear propulsion program is less than the one curie per year U.S. Atomic Energy Commission (USAEC) regulations in reference 2 permit a licensee to discharge into a single sanitary sewage system.

Procedures for Liquid Wastes in Harbor

Discharge limits for radioactive liquid wastes from U. S. Naval nuclear-powered ships and their support facilities are consistent with applicable recommendations issued by the Federal Radiation Council (incorporated in Environmental Protection Agency late in 1970) U. S. Atomic Energy Commission, National Council on Radiation Protection and Measurements, International Commission on Radiological Protection, International Atomic Energy Agency, and National Academy of Sciences - National Research Council (references 2, 3, 4 and 11 through 14). In consonance with these recommendations, the policy of the U. S. Navy is to minimize the amounts

TABLE 1

RADIOACTIVE LIQUID WASTE DISCHARGED TO HARBORS FROM U. S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES FOR 1966 THROUGH 1970

Locations	1966 Thousand Gallons	1966 Curies	1967 Thousand Gallons	1967 Curies	1968 Thousand Gallons	1968 Curies	1969 Thousand Gallons	1969 Curies	1970 Thousand Gallons	1970 Curies
Portsmouth, New Hampshire Naval Shipyard	155	.011	265	.012	171	.006	87	.002	68	.002
Groton-New London, Conn. Electric Boat Div., Tender at State Pier, & Sub Base	1274	.025	606	.011	469	.006	615	.006	359	.004
Newport News, Virginia Newport News Shipbuilding	1581	.055	1533	.034	1146	.025	870	.022	1466	.013
Norfolk, Virginia Naval Shipyard and Tender	1051	.023	1784	.034	184	.004	102	.005	98	.001
Charleston, South Carolina Naval Shipyard and Tenders	369	.034	320	.011	227	.004	131	.001	58	< .001
Pascagoula, Mississippi Ingalls Nuclear Division	< 1	< .001	6	< .001	9	< .001	8	< .001	7	< .001
San Diego, California Tenders at Ballast Point	18	.001	28	.001	< 1	< .001	< 1	< .001	< 1	< .001
Long Beach, California Naval Shipyard and Base	8	< .001	< 1	< .001	< 1	< .001	2	< .001	< 1	< .001
Vallejo, California Mare Island Naval Shipyard	270	.187	140	.001	391	.027	80	.001	121	.002
Bremerton, Washington Puget Sound Naval Shipyard	54	< .001	246	.00[illegible]	182	.001	152	.001	136	< .001
Pearl Harbor, Hawaii Naval Shipyard and Sub Base	654	.031	683	.008	886	.006	1279	.008	258	.002
Apra Harbor. Guam	39	< .001	42	.002	26	.001	< 1	< .001	< 1	< .001
All other harbors, U.S. & Foreign	**178**	**.013**	<1	< .001	<1	< .001	<1	< .001	< 1	< .001
TOTALS	5651	0.381	5653	0.116	3691	0.081	332[illegible]	0.048	2571	0.024

NOTES:

(1) Radioactivity data has been standardized to cobalt 60 and excludes tritium. Volumes are prior to dilution.

(2) A total of 0.02 curie was discharged into the river at Quincy, Massachusetts from 1961 through March 1969 when all work on U. S. Naval nuclear-powered ships was discontinued at General Dynamics, Quincy Division.

(3) A total of 0.01 curie was discharged into the river near Camden, New Jersey from 1960 through June 1967 when all work on U. S. Naval nuclear-powered ships was discontinued at New York Shipbuilding Corporation.

(4) Slight differences in volumes and radioactivity data from past reports result from using more significant figures in this Table. Volumes less than 500 gallons are shown as <1 thousand. Curies less than .0005 are shown as <.001.

of radioactivity discharged within twelve miles from shore including into harbors. Keeping discharges small minimizes the radicactivity available to build up in the environment or to concentrate in marine life. To implement this policy of minimizing discharges, the Navy has issued standard instructions defining the radioactive waste disposal limits and procedures to be used by U. S. Naval nuclear-powered ships and their support facilities. These instructions were reviewed and concurred in by the U. S. Public Health Service and the U. S. Atomic Energy Commission.

To achieve low discharges, the waste disposal procedures and limits used in the Navy nuclear propulsion program are more stringent than in the preceding references. The following are some of the procedures required by the Navy in shipyards:

a. Shipyard management at all levels is required to be involved in control of radioactive liquid waste.

b. Liquids are segregated to minimize volumes required to be processed as radioactive. Liquids with different chemical contents are collected separately to ensure the most effective waste treatment is used. Dilution is not permitted as a means of processing wastes.

c. Several stages of filtration using various pore size filters are used to remove small size radioactive particles in liquid waste. Ion exchange resin and activated carbon are normally used to remove radioactivity from liquid wastes.

d. Each shipyard has a limit specified for the total amount of radioactivity to be discharged during the year.

e. Samples are collected during processing to ensure liquid wastes are far below the permissible water discharge limits in reference 2. Typical limits used by shipyards are 30 times lower than in reference 2.

f. To ensure against operational error, liquid wastes which have been completely processed are transferred to a final clean tank and again sampled prior to discharge. Discharge from this tank is through a final filter.

g. Each discharge requires formal approval of a discharge permit signed by a designated senior radiological control person.

h. An independent organization within the shipyard audits all aspects of radioactive waste processing. This audit group is separate from the radiological control organization which monitors the actual waste processing work.

i. Audits are also performed by representatives from Naval Reactors headquarters who are assigned full time at each shipyard.

j. To ensure absolute compliance with even the smallest detail of operating procedures, each discrepancy found is brought to management attention for action. Aggressive action on such minor items prevents incidents from occurring.

Other Radionuclides

Reactor coolant also contains short-lived radionuclides with half-lives of seconds to hours. Their highest concentrations in reactor coolant are from nitrogen 16 (7 second half-life), nitrogen 13 (10 minute half-life), fluorine 18 (1.8 hour half-life), argon 41 (1.8 hour half-life), and manganese 56 (2.6 hour half-life). For the longest-lived of these, about one day after discharge from an operating reactor the concentration is reduced to one thousandth of the initial concentration and in about two days the concentration is reduced to one millionth. Most discharges from ships occur during heating up prior to power operation of the reactor, when short-lived radionuclides are at low concentrations in coolant. Total short-lived radioactivity in such a discharge is less than 0.001 curie. Because of their small amounts and rapid decay, short-lived radionuclides are less important than long lived radionuclides for waste disposal considerations.

Fission products produced in the reactor are retained metallurgically bound within the fuel alloy. The fission gases krypton and xenon are also retained within the fuel elements. However, trace quantities of naturally occurring uranium impurities in reactor structural materials release small amounts of fission products to reactor coolant. The concentrations of fission products and the volumes of reactor coolant discharged are so low, however, that the total radioactivity attributed to long-lived fission product radionuclides strontium 90 and cesium 137 in discharges from U. S. Naval nuclear-powered ships and their support facilities has been less than 0.001 curie per year for all harbors combined. Fallout of these same fission products has often been more than this in one rainfall in a single harbor.

Small amounts of tritium are formed in reactor coolant systems as a result of neutron interaction with the approximately 0.015 percent of naturally occurring deuterium present in water, and other nuclear reactions. Although tritium has a 12 year half-life, the radiation produced is of such low energy that the radioactivity concentration guide issued by the International Commission on Radiological Protection, the USAEC and by other standard-setting organizations is one hundred times higher for tritium than for cobalt 60. This tritium is in the oxide form and therefore completely soluble in water; it does not concentrate significantly in marine life or collect on sediment since it is chemically indistinguishable from water.

Tritium is naturally present in the environment because it is generated by cosmic radiation in the upper atmosphere. Reference 15 reports that the production rate from this source is about six million curies per year, which through rainfall causes a tritium inventory in the oceans of about one hundred million curies. Because of this naturally occurring tritium, large discharges of tritium would be required to make a measurable change in the background tritium concentration.

The total amount of tritium discharged during each of the last 5 years from all U. S. Naval nuclear powered ships and their supporting tenders, bases and shipyards has been less than 200 curies. Most of these discharges have been in the ocean greater than twelve miles from shore. This total tritium discharged from the entire nuclear Navy is less than a single typical electrical generating nuclear power station discharges each year (reference 10). As described above, such discharges are too small to increase measurably the tritium concentration in the environment. Therefore tritium has been excluded from the data in other sections of this report.

Liquid Waste at Sea

Radioactive liquid wastes are also discharged at sea under strict controls. These ocean discharges are consistent with recommendations the Council on Environmental Quality made in 1970 to the President in reference 16. Procedures and limits for ocean discharges have been consistent with recommendations made by the National Academy of Sciences - National Research Council in reference 12 and by the International Atomic Energy Agency in reference 13. Ship discharges have contained much less radioactivity than these reports considered would be acceptable. Total long-lived radioactivity excluding tritium discharged farther than twelve miles from shore by all U. S. Naval nuclear-powered ships and their supporting tenders is shown in Table 2 for recent years.

TABLE 2

Radioactive Liquid Waste Discharged at Sea
by U. S. Naval Nuclear-Powered Ships
and Supporting Tenders

	Thousand Gallons	Curies
1966	1400	1.2
1967	1520	1.3
1968	1630	1.1
1969	1570	1.7
1970	1220	0.8

Reactor coolant is purified through an ion exchange resin bed. This resin becomes expended and periodically requires replacement. Expended resin has been discharged at sea, but this practice was discontinued during 1970. When discharged at sea, resin sinks and as it sinks, the radioactive ions in the resin are rapidly replaced by ions of the sea water. Some of the small radioactive particles in the resin bed are dispersed in sea water and the rest sink with the resin beads. The radioactivity is rapidly dispersed in the ocean due to motion of ship during discharge and subsequent action of wind, waves and ocean currents.

Resin discharge at sea was performed in accordance with procedures recommended in the National Academy of Sciences - National Research Council Publication 658, "Radioactive Waste Disposal from Nuclear-Powered Ships" reference 12. Consistent with these recommendations, Navy procedures for resin discharge at sea required:

(1) the ship be more than 12 miles from any land,

(2) the water depth be greater than 1200 feet,

(3) the ship not be in known fishing areas, and

(4) other ships not be nearby and will not be in the wake.

Publication 658 developed these procedures to assure no adverse impact on the environment if up to 300 nuclear-powered ships each discharge 400 curies of radioactivity every 2 months off the shores of the United States.

Table 3 summarizes resin discharges at sea during the last five years. These results show that the total radioactivity discharged in resin by the entire Navy each year has been less than envisaged in the National Academy of Sciences report for a single ship. Diluting this total radioactivity discharged in a year in a volume as small as one cubic mile of seawater reduces the concentration of radioactivity to less than occurs naturally in the ocean. Continued effort by the Navy resulted in improvements in 1970 which have permitted discontinuing discharge of ion exchange resin at sea. Expended resin is now packaged for land disposal in USAEC or State licensed burial grounds as solid radioactive waste.

TABLE 3

Radioactive Resin Disposal at Sea by U. S. Naval Nuclear-Powered Ships

	Cubic Feet of Resin	Curies
1966	119	439
1967	252	259
1968	196	126
1969	406	132
1970	150	60

Two U. S. Navy nuclear powered submarines have been lost at sea in the Atlantic Ocean. The submarine THRESHER sank 10 April 1963, 100 miles from land in water 8,500 feet deep at latitude 41°45'N and longitude 65°00'W. The submarine SCORPION sank between 21 and 27 May 1968, 400 miles southwest of the Azores in more than 10,000 feet of water. The reactors used in all U. S. Naval submarines and surface ships are designed to minimize potential hazards to the environment even under the most severe casualty conditions such as actual sinking of the ship. First, the reactor core is so designed that it is physically impossible for it to explode like a bomb. Second, the reactor fuel elements are made of materials that are extremely corrosion resistant, even in sea water. The reactor core could remain submerged in sea water for decades without release of fission products while the radioactivity decays, since the protective cladding on the fuel elements corrodes only a few millionths of an inch per year. Thus in the event of a serious accident where the reactor is completely submerged in sea water, the fuel elements will remain intact for an indefinite period of time and the radioactive material contained in these fuel elements should not be released. The maximum rate of release and dispersal of the radioactivity in the ocean, even if the protective cladding on the fuel were destroyed, would be so low as to be insignificant.

Radioactive material could be released from this type of reactor only if the fuel elements were actually to melt and in addition the high-strength, all-welded reactor system boundary were to rupture. The reactor's many protective devices and inherent self-regulating features are designed to prevent any melting of the fuel elements. Flooding of a reactor with sea water furnishes additional cooling for the fuel elements and so provides added protection against the release of radioactive material.

Radiation measurements, water samples, bottom sediment samples and debris collected from the area where THRESHER sank were analyzed for radioactivity by various laboratories with highly sensitive equipment. Similarly, sea water and bottom sediment samples taken near SCORPION's hull were analyzed for radioactivity. None of these samples showed radioactivity above naturally occurring background levels and none showed evidence of radioactivity released from either THRESHER or SCORPION.

SOLID RADIOACTIVE WASTE DISPOSAL

During maintenance and overhaul operations, solid low-level radioactive wastes consisting of contaminated rags, plastic bags, paper, filters, ion exchange resin and scrap materials are collected by nuclear-powered ships and their support facilities. High-level radioactive wastes are associated with expended reactor fuel, all of which is transferred to the USAEC for processing. Solid materials from ships are not dumped at sea. They are packaged in a support facility or transferred to a shipyard for packaging. For ultimate disposal, the packaged solid radioactive wastes are shipped to burial sites licensed by the USAEC or a State under agreement with USAEC since shipyards and shore facilities are not permitted to dispose of radioactive solid wastes by burial on their own sites. Table 4 summarizes total radioactivity and volumes of radioactive solid waste disposal for the last five years.

Because of efforts to minimize solid waste, total volumes have remained nearly constant in spite of increasing work caused by increasing numbers of ships. The average annual volume for the entire Naval nuclear propulsion program could be contained in a cube measuring fifteen yards on a side. The radioactivity does not require excessively long time care in the licensed burial grounds since the principal radionuclides do not have half-lives longer than five years. In one hundred years, such radioactivity will have decayed to one millionth the initial radioactivity. In less than two hundred years, the total of all radioactivity in Table 4 will have decayed to less than the amount of radioactivity in a single luminous watch dial.

Disposal of solid radioactive wastes at sea is prohibited by the U. S. Navy. There have been two special exceptions to this policy. First on 8 April 1959 the radioactive reactor vessel and reactor plant components removed from the sodium-cooled nuclear reactor plant in the submarine SEAWOLF were escorted by the U. S. Coast Guard to a disposal site in the Atlantic Ocean 120 miles off the East Coast of the U. S. and sunk in 9,000 feet of water at latitude 38°30'N and longitude 72°06'W. The disposal was conducted at a site approved for sea disposal of radioactive waste by USAEC. This disposal site was used by other organizations for a number of years for radioactive waste as noted in reference 16. The SEAWOLF components containing approximately 33,000 curies of radioactivity were welded into a steel barge and scuttled. The low corrosion of this steel container in seawater and the method of packaging were designed to prevent any release of radioactivity to the surrounding sea. As of 1970 this radioactivity has decayed to less than 5,000 curies, essentially all cobalt 60.

TABLE 4

RADIOACTIVE SOLID WASTE FROM U. S. NAVAL NUCLEAR-POWERED SHIPS AND THEIR SUPPORT FACILITIES FOR 1966 THROUGH 1970

Facility	1966 Thousand Cubic Feet	1966 Curies	1967 Thousand Cubic Feet	1967 Curies	1968 Thousand Cubic Feet	1968 Curies	1969 Thousand Cubic Feet	1969 Curies	1970 Thousand Cubic Feet	1970 Curies
Portsmouth, New Hampshire Naval Shipyard	19	10	30	198	31	151	8	3	14	16
Groton, New London, Conn. Electric Boat Div., Tender at State Pier, & Sub Base	15	1093	5	17	4	21	8	328	12	140
Newport News, Virginia Newport News Shipbuilding	7	9	17	702	14	10	17	382	28	312
Norfolk, Virginia Naval Shipyard and Tender	4	3	11	86	2	11	6	8	9	146
Charleston, South Carolina Naval Shipyard and Tenders	8	6	15	52	14	110	15	9	8	6
Pascagoula, Mississippi Ingalls Nuclear Division	0	0	0	0	0	0	1	< 1	0	0
San Diego, California Tenders at Ballast Point	1	< 1	1	< 1	1	8	< 1	2	< 1	1
Long Beach, California Naval Shipyard and Base	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Vallejo, California Mare Island Naval Shipyard	9	367	9	23	8	7	8	5	12	2
Bremerton, Washington Puget Sound Naval Shipyard	1	1	14	193	14	48	11	42	18	1327
Pearl Harbor, Hawaii Naval Shipyard & Sub Base	1	< 1	1	1	3	6	4	3	5	4
TOTALS	65	1489	103	1272	92	372	78	783	106	1954

NOTES:

(1) This table includes all radioactive waste from tenders and nuclear-powered ships. This radioactivity is primarily cobalt 60.

(2) Slight differences from past reports result from using different number of significant figures in this table. Volumes less than 500 cubic feet are reported <1 thousand and less than 0.5 curie is reported <1.

The second exception was required for radioactive solid wastes from Pearl Harbor since it was not feasible to establish a burial ground in the volcanic rocks of Hawaii. Therefore an ocean disposal area 55 miles from shore was selected with the agreement of the USAEC, the U. S. Public Health Service, and the Hawaii Department of Health. The Navy Hydrographic Office determined that normal ocean currents at this location are away from shore. Low-level radioactive waste packaged primarily in fifty-five gallon steel drums weighted with concrete were disposed of by Pearl Harbor Naval Shipyard in 15,000 feet of water at this location, as shown in Table 5. The radioactivity in this waste was primarily cobalt 60. In June 1968 use of this ocean disposal area was discontinued by the Navy and wastes have since been shipped to a USAEC or State licensed land burial ground in the continental U. S.

TABLE 5

Solid Radioactive Waste Disposal in the Ocean
at Latitude 20°54'N Longitude 161°06'W

Year	Number of Disposal Operations	Volume cubic feet	Curies
1963	1	1647	0.5
1964	1	1275	0.7
1965	1	672	1.4
1966	1	682	0.3
1967	2	1134	1.0
1968	4	1720	4.5
TOTAL	10	7130	8.4

ENVIRONMENTAL MONITORING

Environmental monitoring surveys for radioactivity are periodically performed in harbors where U. S. Naval nuclear-powered ships are built or overhauled and where these ships have home ports or operating bases. These surveys are performed to verify the adequacy of liquid waste disposal procedures and limits. To ensure thoroughness and objectivity these surveys are made as independent as practicable from waste disposal operations. Samples from each harbor monitored are also checked at least annually by a U. S. Atomic Energy Commission (USAEC) laboratory to ensure analytical procedures are correct and standardized. These USAEC laboratory results have been consistent with shipyard results. As a further independent check of environmental monitoring the U. S. Public Health Service (USPHS) has conducted detailed surveys of selected harbors (references 17 and 18). USPHS has monitored the harbors at Charleston, South Carolina; Pearl Harbor, Hawaii; San Diego, California; Vallejo, California; New London, Connecticut; Newport News, Virginia; and Norfolk, Virginia. Navy monitoring results have been consistent with these USPHS surveys.

The Navy monitoring program initially emphasized analyzing water because it is used by boats and swimmers and because fish live in this water. Surveys were conducted in the harbors before any radioactivity was discharged, to establish base levels of gross beta activity of harbor water in the vicinity of berths to be used by nuclear-powered ships and locations where support facilities might discharge processed water. Results showed that superimposed on the naturally occurring radioactivity of 0.3 picocurie* of potassium 40 per milliliter of harbor water were large variations of other radioactivity from fallout. Rainwater before much dilution in harbor water sometimes has measured more than 100 times higher than this. In addition rates of introduction of naturally radioactive radium, uranium, thorium and their associated radionuclides varied. However, in more than ten years of monitoring seawater for gross beta activity commencing in 1954 in New London, Connecticut, and extending to other ports, no increase in water radioactivity was ever discovered which could be attributed to operation of nuclear-powered ships or their support facilities.

Although the general background radioactivity measurements previously used would indicate presence of radioactivity before exceeding concentrations permitted in reference 2, more sensitive measurement techniques were adopted in 1965. Currently, five water samples are taken in each harbor once each quarter year in areas where nuclear-powered ships berth and from upstream and downstream locations. These samples are analyzed for gross gamma radioactivity and for cobalt 60 content. Procedures for analysis were selected to detect cobalt 60 if its concentration exceeds 0.1 picocurie per milliliter, which is 300 times lower than the USAEC limit of reference 2. No cobalt 60 has been detected in any of the 2560 water samples from 20 harbors monitored.

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* One picocurie equals 10^{-12} curie, or one millionth of one millionth of a curie.

Harbor bottom sediment contains many of the remnants of water pollution; the top layer is generally black and has an offensive odor from decomposing organic waste materials. Silt carried by rivers also deposits on harbor bottoms, building up in depth from less than one inch per year to more than three feet per year. In falling to the bottom, this silt carries radioactivity from the water to the bottom. Therefore sampling of harbor bottom sediment became part of early Navy environmental monitoring programs to provide advance indication of radioactivity buildup in the harbor.

Initially, dried samples of harbor bottom sediment were measured for gross beta radioactivity. Results varied from 10 picocuries per gram of sediment to 300 picocuries per gram, and varied widely from sample to sample and from month to month in a single harbor. However, analysis of these data showed no harbor had increased its general background radioactivity from operations associated with U. S. Naval nuclear-powered ships.

Commencing in 1963 at Navy request, the USPHS made additional analyses of samples from some harbors to identify radionuclides present in sediment. These analyses showed cobalt 60 was the predominant radionuclide added to sediment from nuclear reactor operations. Therefore Navy monitoring procedures were changed to collect in each harbor 20 to 120 sediment samples once each quarter year. Standard six inch square samplers modified to collect only the top one-half to one inch of sediment are used for all sediment collection. The top layer was selected because it should be more mobile and more accessible to marine life than deeper layers. The samples are analyzed for gross gamma radioactivity and for cobalt 60. Results of the 3070 sediment samples from harbors in the U. S. and possessions for 1970 are summarized in Table 6. Comparison to previous environmental monitoring data in references 5 through 9 shows that environmental cobalt 60 levels have been steadily decreasing.

TABLE 6

SUMMARY OF 1970 SURVEYS FOR COBALT 60 IN BOTTOM SEDIMENT OF U. S. HARBORS WHERE U. S. NAVAL NUCLEAR-POWERED SHIPS HAVE BEEN REGULARLY BASED, OVERHAULED OR BUILT

	Number of Samples with Cobalt 60			Total Bottom Area with Cobalt 60 over 3 pCi/g** (Square Kilometers)	Estimated Total*** Cobalt 60 in Top Layer of Sediment (Curies)
	less than 3 pCi/g*	between 3 & 30 pCi/g	30 to 300 pCi/g #		
Portsmouth, New Hampshire Naval Shipyard	176	0	0	0	ND
Groton, New London, Conn. Electric Boat Division, State Pier, and Submarine Base	377	86	1	0.1	0.02
Newport News, Virginia Newport News Shipbuilding	152	0	0	0	ND
Norfolk, Virginia Naval Shipyard and Base	344	0	0	0	ND
Charleston, South Carolina Naval Shipyard and Bases	382	0	0	0	ND
Pascagoula, Mississippi Ingalls Nuclear Division	212	0	0	0	ND
San Diego, California Navy Pier at Ballast Point	157	0	0	0	ND
Long Beach, California Naval Shipyard and Base	158	0	0	0	ND
Vallejo, California Mare Island Naval Shipyard	444	0	0	0	ND
Bremerton, Washington Puget Sound Naval Shipyard	141	0	0	0	ND
Pearl Harbor, Hawaii Naval Shipyard and SubBase	312	0	0	0	ND
Apra Harbor, Guam	128	0	0	0	ND

NOTES:

* Minimum detectable radioactivity is approximately 1 pCi/g (picocurie per gram). Results in units of pCi/cm^2 range from two to four times the value of pCi/g.

** One square kilometer is approximately equal to 0.4 square mile. Areas with cobalt 60 over 3 pCi/g were in immediate vicinity of piers used for berthing nuclear-powered ships.

*** Where total cobalt 60 in the surface sediment layer is less than 0.01 curie, ND is reported. Samples more than one foot deep from several harbors show that total cobalt 60 present may be two to five times that measured in the surface layer.

# No samples from any harbor were greater than 31 pCi/g.

Table 6 shows that some samples taken near liquid waste discharge points show cobalt 60 radioactivity. However, the affected areas are small and the total cobalt 60 present is small compared to natural radioactivity present in harbors.

The first data column in Table 6 includes all samples with less than three picocuries of cobalt 60 per gram of sediment. These low levels are difficult to measure because the levels of radioactivity in sediment from other sources are much higher. The value of 30 picocuries per gram was selected for the top of the second range of data since it corresponds to the upper limit for exposure in references 2 and 4 even if consumed continuously by members of the general public. Although sediment can not be consumed by humans, it might serve as a food source for marine life. Data on uptake of cobalt 60 from sediment by marine life obtained to date show that in the salt water harbor bottom environments, no significant buildup of cobalt 60 occurs in marine life. Therefore the third range of up to 300 picocuries per gram is selected as a range which would not cause members of the general public to receive radiation exposure approaching the values set in references 2, 3, 4 and 14. Concentrations of cobalt 60 up to 300 picocuries per gram are so low that the USAEC does not require those who might possess them to be licensed. If concentrations higher than 300 picocuries per gram were to persist over substantial areas of a harbor bottom, further monitoring would be performed to determine if any of this radioactivity were being taken up by marine life for eventual consumption in food. Because of the low concentrations noted in Table 6, monitoring of radioactivity in marine life has not been necessary as part of the routine environmental monitoring programs in these harbors.

References 19 and 20 contain evaluations by USAEC laboratories of the effects on the environment from the accumulation near points of discharge of radionuclides from several other nuclear reactors. These reports conclude for these other reactors that radioactivity levels much greater than shown in Table 6 have caused no significant exposure to the general public.

An additional part of the environmental analyses has been to compare amounts of radioactivity measured in the environment with amounts discharged, as in the following example. If 0.01 curie were discharged each year for more than ten years into a single harbor, the maximum total inventory of cobalt 60 in this harbor will be 0.1 curie of cobalt 60, assuming none of this radioactivity is flushed out with river currents, tides, or dredging. If all this radioactivity were spread uniformly over a reasonable area of one square kilometer of the harbor bottom, the result would be less than ten picocuries of cobalt 60 per square centimeter. This cobalt 60 will be distributed deeply through the sediment over the years, resulting in an average concentration less than one picocurie of cobalt 60 per gram of sediment. This is less than the amount of cobalt 60 which would be detected by present sensitive environmental monitoring techniques. Results of analyses such as these help confirm the environmental monitoring data of Table 6 and confirm that the Navy's waste discharge limits are satisfactory.

In all monitored harbors, twice per year shoreline areas uncovered at low tide are surveyed for radiation levels with sensitive radiation detectors to determine if any radioactivity from bottom sediment washed ashore. All results were the same as background radiation levels in similar areas, 0.01 to 0.04 millirem per hour. Thus there is no evidence in these ports that radioactivity from sediment is washing ashore.

Film badges are continuously posted at locations outside the boundaries of areas where radioactive work is performed. These films showed that radiation exposure to the general public outside these facilities was not above that received from natural background radiation levels.

Naval nuclear reactors and their support facilities are designed to ensure there are no detectable discharges of airborne radioactivity to the atmosphere. Filtration equipment is installed in support facilities to ensure removal of airborne radioactivity without release to the atmosphere. Exhaust stacks at support facilities which could have discharged airborne radioactivity have been monitored. There were no discharges of airborne radioactivity to the atmosphere measured above concentrations normally present in the atmosphere.

In addition to the locations listed in Table 6, environmental monitoring is performed by U. S. Navy submarine tenders which serve as operating bases for U. S. Naval nuclear-powered submarines in Rota, Spain and Holy Loch, Scotland. Results of the surveys in the harbor at Rota, Spain have not shown detectable cobalt 60 in harbor bottom sediment samples. In 1965 in Holy Loch, more cobalt 60 radioactivity than expected was detected in harbor bottom sediment and on shoreline mud flat areas uncovered at low tide. However, there had been no increase of harbor water radioactivity in Holy Loch above normal background levels. Joint U. S. and British assessments of survey results confirmed that radiation levels in the vicinity of the Holy Loch anchorage were far below those which were at all likely to cause an individual to receive radiation exposure approaching limits for members of the general public. Environmental monitoring during 1970 showed radioactivity levels in Holy Loch are steadily declining and are now less than half the levels in 1965.

CONCLUSIONS

1. The total radioactivity discharged into all ports and harbors from the U. S. Naval nuclear propulsion program was 0.024 curie in 1970.

2. No increase of radioactivity above normal background levels has been detected in harbor water where U. S. Naval nuclear-powered ships are based, overhauled, or constructed.

3. Discharges of liquid wastes from U. S. Naval nuclear-powered ships have not caused a measurable increase in the general background radioactivity of the environment.

4. Low-level cobalt 60 radioactivity in harbor bottom sediment is detectable around a few piers at operating bases and shipyards where nuclear-powered ship maintenance and overhauls have been conducted over a period of several years. Cobalt 60 is not detectable above background levels in general harbor bottom areas away from these piers. Maximum total radioactivity observed in a U. S. harbor is less than one curie of cobalt 60. Comparison to previous environmental monitoring data in references 5 through 9 shows that these environmental cobalt 60 levels have been steadily decreasing.

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APPENDIX A-14

POWER UTILITIES

These industries are responsible for providing and distributing energy, essential to the stimulation and support of economic development. The United States consumes about 35 percent of the world's total energy product. In 1970, this amounted to approximately 685 times 10^{15} Btu of energy, derived almost in its entirety from fossil fuels. Of this energy total, almost one-third is provided in the form of electricity, 50 percent of which is generated using coal as the energy source, 20 percent using petroleum, 10 percent using natural gas, and the remaining 20 percent generated by water power. A small amount is derived from the use of nuclear fuels (Reference 1).

The industrial consumption pattern for the fossil fuels indicates that most of the coal is used to generate electricity, while petroleum and natural gas are used directly for space heating and to provide automotive power for vehicles. This section will discuss two types of power utilities: electric and natural gas.

1. ELECTRIC UTILITIES

Presently, electric power accounts for about one-third of the total energy supply. Table A-14-1 summarizes the availability of electric energy in the United States, as of 1966 (Reference 2). The availability of power and type of ownership are given for the following specific geographic areas:

North East - Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut
Middle Atlantic - New York, New Jersey, and Pennsylvania
East North Central - Ohio, Indiana, Illinois, Michigan, and Wisconsin
West North Central - Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas
South Atlantic - Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida
East South Central - Kentucky, Tennessee, Alabama, and Mississippi
West South Central - Arkansas, Louisiana, Oklahoma, and Texas
Mountain - Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada
Pacific - Washington, Oregon, California, Alaska, and Hawaii

Table A-14-1
Electric Energy, Power Source and Ownership[1]

Geographical Area	Millions of Kilowatt Hours					
	Electric Utilities		Total	Ownership		
					Public	
	Fuel	Hydro		Private	Municipal	Other
North East	38,945	4,444	47,942	42,564	685	140
Middle Atlantic	143,555	23,038	166,593	147,363	831	18,399
East North Central	230,810	3,654	234,464	224,540	7,275	2,649
West North Central	57,294	10,368	67,662	46,317	6,204	15,141
South Atlantic	158,607	12,861	171,468	159,502	6,290	5,676
East South Central	100,486	17,099	117,584	35,523	1,361	80,700
West South Central	110,266	2,886	113,152	99,060	7,881	6,211
Mountain	26,602	24,565	54,167	36,514	1,220	16,433
Pacific	80,030	95,842	175,872	89,456	20,879	65,538
Total	946,594	194,756	1,148,900	880,837	52,627	210,886

[1] Reference 2.

Table A-14-2 gives a breakdown in the consumption of fossil fuels, by the electric industry for 1966 and 1967 (Reference 2). Also shown, is the amount of fuel that was required per kilowatt-hour of electricity.

The projected growth in demand for electricity in millions of kilowatt-hours is: for 1975 – 2,166,000; for 1980 – 3,061,000; for 1985 – 4,238,000; and for 1990 – 5,828,000. The current annual growth rate for electrical energy is 9 percent. This means that the capacity must double in the next eight years. The Federal Power Commission estimates that within 20 years an additional 300 power stations of 3,000 Mw each, and an additional 7 million acres of new land for electric transmissions, will be required. Assuming a 10-degree rise in cooling water for the additional capacity, and without the use of wet or dry cooling towers, the total water required would approximate 5 times 10^{14} gallons per year. This is equivalent to the annual runoff from 48 contiguous states, and cannot be made available within the next 20 years (Reference 3).

The use of nuclear fuels compounds this problem, in that those likely to be used in this time frame are less efficient in converting heat into electrical power, and hence add more of the energy into the environmental waters.

2. GAS UTILITIES

The gas utility industry handles various types of gas distributed as an energy source. Table A-14-3 shows a breakdown of gas, types together with the energy content, revenues, and the customer distribution for each commodity (Reference 2).

Table A-14-2
Consumption of Fossil Fuels by Electric Utilities, 1966-1967

Year	Fuel Generated (mil. kw-hr)	Coal (Short Tons)			Oil 42 Gal bbls.	Gas Mil-Ft^3	Per Kw-hr.		
		Anthra.	Bit. & Lig.	Total			Coal (lb.)	Oil (Gal)	Gas Ft^3
1966	949, 594	2, 192	264, 285	266, 477	140, 949	2, 609, 945	.869	.075	10.4
1967	991, 706	2, 186	271, 787	273, 973	161, 275	2, 743, 251	.870	.076	10.4

Table A-14-3

Gas Utility Industry Customers, Energy, and R[illegible]ue, 1966

Type of Gas	Customers (1,000)				Quantity	Revenues
	Resident.	Commercial	Industrial	Total	(Mil-Therms)	(Mil. Dol.)
SIC 4922 - Natural	34,471	2,827	172	37,513	127,525	7,745
SIC 4925 - Manufactured	91	7	1	99	89	16
- Mixed	540	31	1	574	1,297	111
- Liquid Petroleum	40	3	-	43	22	5
Total	35,142	2,868	174	38,228	128,932	7,878

Table A-14-4 gives a breakdown of the geographical distribution of the gas utilities in the United States, together with the power consumption and associated revenues (Reference 2).

The future of the gas industry depends largely on technological advances. The industry, as it is now known (as a direct fuel for space heating, etc.), may decline as electric generation grows, due to better conversion efficiency and environmental acceptability of coal, petroleum, and nuclear fuels. On the other hand, the demand for gas may increase, markedly, if gas fuel-cells are used to produce electrical power efficiently onsite, or where the environmental problems of coal, petroleum, or nuclear fuels become acute and retard the growth of the central powers generation concept.

3. POWER RESOURCES

Electric power is generated from the following resources:

Coal
Petroleum and natural gas
Uranium
Hydropower
Geothermal power

(1) Coal

- Anthracite - In 1968, the U. S. production was 11,591 thousand short tons, with a domestic demand for 10,160 thousand short tons. Of this demand, the electric utility industry consumed 2,203 thousand short tons or about 22 percent. The projected demand, for the year 2000, is estimated to be

Table A-14-4

Gas Utility Distribution of Customers, Energy and Revenue, 1966

Geographical Area	Customers (1,000)				Quantity	Revenues
	Resident	Commercial	Industrial	Total	(Mil-Therms)	(Mil. Dol.)
North East	1,536	98	10	1,645	1,800	285
Middle Atlantic	7,387	558	30	7,987	13,597	1,406
East North Central	7,995	618	37	8,657	29,709	2,141
West North Central	2,858	273	21	3,153	13,970	729
South Atlantic	2,841	241	14	3,104	9,532	691
East South Central	1,583	160	6	1,756	8,152	402
West South Central	4,003	383	34	4,424	25,174	815
Mountain	1,461	165	7	1,673	7,463	339
Pacific	5,478	373	14	5,866	19,537	1,071

between 1.0 and 3.6 million short tons, based on a continuing decline in coal use. The estimated domestic anthracite reserves amount to 12,969 million tons, and at a 50 percent recovery, amount to 6,485 million tons of this type coal.

- Bituminous and Lignite - Production for 1968 was 637,858 thousand short tons, with a domestic demand for 498,830 thousand short tons. Of this total, the electric utility industry consumed 294,739 thousand short tons or about 58 percent. The anticipated domestic demand for the year 2000 lies between 1,275 to 2,639 million tons. The proven domestic reserves amount to 1,546,906 million short tons of ore, and at a 50 percent recovery amount to 773,453 million short tons of coal. In addition, it is believed that additional reserves of 1,313,080 million tons of coal may exist. Other resources include 337,105 million tons that lie at a depth of 3000 to 6000 feet.

(2) Petroleum and Natural Gas

- Petroleum - The 1968 production of petroleum amounted to 6,008.1 million (42 gal) barrels, with an industrial demand of 4,900.2 million barrels. The chief consumers of petroleum are the household and commercial (2,699.0 million barrels), and transportation (1,149.0 million barrels) sectors. Electric utilities consume only 188.0 million barrels (3.8 percent). The projected domestic demand for petroleum, in the year 2000, is set between 7.3 and 16.4 million barrels. The domestic petroleum reserves include an estimated 30.71 billion barrels of crude oil, 77 percent of which is located in Texas, California, and Louisiana, and 8.60 billion barrels of liquid natural gas, 77.7 percent of which is located in Texas and Louisiana.

- Natural Gas - In 1968 the domestic supply of dry natural gas was set at 21,796,809 million cubic feet, with a demand of 18,957,124 million cubic feet. Of that total, 3,143,858 million cubic feet (33 percent) was consumed by household and commercial industry, and 6,250,997 million cubic feet (16 percent) being used in the electric utility industry. The projected requirement for dry natural gas for the year 2000 is set between 34,800 to 55,700 billion cubic feet. The dry natural gas reserves in the United States are currently estimated at 287.35 trillion cubic feet.

(3) Uranium

The 1968 total domestic production of uranium amounted to 10,463 short tons, with a demand of 2,700 short tons. A total of 2,658 short tons, or about 99.9 percent, of the total demand went into power reactors. For the year 2000, uranium demand is estimated to be between 72,000 and 81,000 short tons. The amount of electricity produced, using radioactive fuel, is very small but, by the year 2000, 40 to 60 percent of electrical power may be derived from this fuel type.

(4) Hydropower

Around 1960, about 20 percent of the electrical energy was generated by water power. Water power is restricted by geographical location, and is not evenly available throughout the year. The Federal Power Commission estimates that the hydro capacity for the 48 contiguous states is 127 million kilowatts. The projection for 1980 is a total installed capacity of 65 million kilowatts. It is not anticipated that the domestic hydro capacity will exceed 90 million kilowatts at any time in the future, because of the increased use of nuclear power. Exploitation of the theoretical capacity of 127 million kilowatts, would produce only 10 percent of the total electrical demand in the year 2000 (Reference 4).

(5) Geothermal Power

This is a natural heat source derived primarily from radioactive decay in the earth. The annual energy flow to the surface of the earth approximates that provided by 170 billion barrels of petroleum. Although these natural steam sources have very little impact on the environment, they are low in atmospheric pollutants and contain no ash, nitrogen, sulfur oxides, or radiation hazards. their use as energy sources are severely limited by geographical location. It is estimated that the worldwide geothermal power capacity driven by geothermal heat now equals about 700,000 kilowatts, and will increase over the next several decades (Reference 5).

4. ASSOCIATED ENVIRONMENTAL POLLUTION

The power utilities contribution to our environmental degradation is shown in Table A-14-5.

Table A-14-5
Type of Pollution by Fuels in Electric Utility Industry

		Air					Water		Solids			
Energy Sources		Carbon Monoxide	Sulfur Oxide	Hydrocarbons	Nitrogen Oxides	Particulates	Thermal	Radiation	Fly Ash	Bottom Ash	Radioactive	Spills
Fossil Fuels	Coal	X	X	X	X	X	X		X	X		
	Petroleum	X	X	X	X	X	X					X
	Nat. Gas				X		X					
	Annual Emissions (Million Tons)	1	12	1	3	3			24	6		1
Radio-Active	Nuclear (Uranium)						X	X			X	
Water Pwr.	Hydro						X					
Natural Heat	Geothermal (Steam)											

(1) Air Pollution

The major chemical contributors to air pollution, emitted by power utilities, are described in the following paragraphs.

Carbon Monoxide - This gas develops due to imperfect combustion of fossil fuels, and is attributed almost entirely to man himself. Although large amounts are emitted, it does not seem to accumulate in the atmosphere. The mechanism for its removal is not well understood.

Sulfur Oxides - These occur as impurities in fossil fuels, and are among the most troublesome of the air pollutants. Sulfur dioxide may form sulfuric acid, or it may react further to form ammonium sulfate. The life of sulfur in the atmosphere is about a week, and when it is removed from the atmosphere by precipitation the acidity of rain fall results, the increase in acidity shows up as water pollutants.

Hydrocarbons - These are produced by combustion of coal, wood, and particularly by the processing and use of petroleum. The reactions of hydrocarbons with nitrogen oxides when acted upon by ultra-violet radiation, produce a photo-chemical smog that is hazardous to health and property. Oil spills add hydrocarbon pollutants in local concentrations, which are toxic to many living organisms. These yearly spills total to about 1 million tons of pollutant, but seem to have no world wide effects. It appears that bacteria degrade the oil rapidly.

Nitrogen Oxides - These are produced in the combustion process, the three most common are nitric oxide, nitrogen dioxide, and nitrous oxide. Nitrogen dioxide, the worse of the three, is a strong absorber of ultraviolet radiation, and also involves photo-chemical reactions causing smog, and when associated with water can produce nitric acid.

Particulates - Solid particles are injected into the lower atmosphere from a number of sources, the utilization of fossil fuels being a major contributer. Pollution technology now available is adequate for limiting such emission.

(2) Water Pollution

The major contributors to water pollution are thermal and radiation emissions.

1. Thermal Pollution

This form of pollution is dissipated into the environment in two ways: through the smoke stacks directly into the atmosphere, and as heated cooling water.

The world's present energy use-rate is approximately 0.01 percent of that which the earth absorbs from the sun and reradiates into outer space to maintain its equilibrium. Present knowledge indicates a use-rate equal to 1 percent that amount would cause concern, while a use-rate 10 percent of that amount would be intolerable. A 3 percent annual increase rate for a period of 150 years would produce the 1 percent rate spoken of earlier. However, in the nortjeastern United States, where 40 percent of the national energy is used, the 1 percent figure has been reached, with no noticable climatic effect. In the Los Angeles area, the 1 percent has been exceeded with no noticeable climatic effects. Thermal pollution is harmful to aquatic and biological activity. The electric power industry is a chief contributer, due to its vast requirement for cooling water.

The present trend to move from the use of fossile fuels to nuclear fuels, for the generation of electrical energy reduces many pollutants, but adds to the problem of thermal pollution because about 40 percent more heat is added to the environment than is the case with fossil fuels (due to conversion efficiency of the nuclear reactors).

(1) Future Outlook for Thermal Pollution. In 1970, a total of $5,596 \times 10^{13}$ Btu of energy produced 1.360×10^{9} Kwh of electric energy, required about 125×10^{9} gallons of cooling water per day, and released 3.720×10^{13} Btu to the environment. Predictions for the year 2000 indicate that 2.510×10^{14} Btu of energy will produce 6.100×10^{9} Kwh of electricity, requiring 677×10^{14} Btu of energy to the environment (Reference 6).

The situation, as described, points up the fact that concerted efforts must be made in the technology associated with fuel processing, combustion and energy conversion, and cooling and heat dissipation facilities. An effort must be made to reduce the consumption of electricity by developing more applications for by-products of energy production now wasted. Failure to carry out advances in these areas will create a large burden for our environmental managers, and may result in the acceptance of further and more serious degradation of our environment.

Development of uses for wasted thermal energy is being pursued in the fields of agriculture (greenhouse, poultry, and swinehouse heating), aquaculture (heating water to stimulate growth of certain marine life), and urban and industrial heating. These uses would require the proximity of a generating plant.

(2) Control of Thermal Pollution. Thermal pollution can and should be controlled through an established environmental control program. Areas to be considered include:

- Reduction of Waste Heat by Improving Thermal Conversion Efficiency — The efficiency with which energy fuels are being converted into electricity have been undergoing improvement with time. In 1938, it required 16,500 Btu to produce 1 Kw of electricity, by 1970 this amount was reduced to 10,000 Btu's and, by 1980, the Federal Power Commission predicts the requirement to drop to 8,500 Btus, however with these improvements by 1980, 60 percent of all energy used to generate electricity will be wasted.

- Management of Heat Waste in the Environment — Methods to reduce the degrading effect of heat waste on the environment must be developed. These could include efforts to provide turbulence in receiving waters, injection of heated effluent into deep portions of the receiving waters, construction of dams, and even shuting down power-plants during certain periods of the year.

Improvement of Heat Disposal Techniques — Presently heat disposal consists of the once-through system and closed-cooling cycle. The Once-Through-System is used where water is readily available. Water is brought in from the water source, used for cooling and discharged back into the water course. The advantage of this system is low water consumption, control of temperature to meet biological objectives, and dissipation of heat into the atmosphere over a large area. The Closed Cycle System includes cooling ponds, spray systems, wet draft towers, and dry draft towers. Cooling ponds are used primarily in the southwest where vast land areas and low humidity provide good cooling characteristics. Spray systems are used to increase heat dissipation, however, water loss from evaporation and drift are considerable. There are two types of wet draft towers, natural and mechanical. In the natural type, cooling is accomplished by using natural draft or air passing through water droplets. Cooling is by evaporation, consuming about 2-1/2 times as much water as the once-through process, and 3 percent of the total water must be replaced due to loss. A 1,000 Mw plant requires 30 million gallons daily, which today is acceptable but may not be in 20 or 30 years. The mechanical cooling systems are smaller in size than natural tower systems. Air is forced through the spray by motor driven fans. Capital costs are lower than natural but operating costs are higher. There are problems with fog and ice in humid areas. Dry draft towers are appreciably larger (350 feet high and 325 feet in diameter) than the wet towers, and cost three to five times more. This technique avoids the difficulties of evaporation and water draft loss, however, warm areas inflict a severe penalty on thermal efficiencies.

2. Radiation Pollution

Most radioactivity is in the form of fission products of uranium dioxide fuel. Some are refractory oxides insoluble in water, while others are not only soluble but volatile. These wastes have a very high level of activity with a heat output of about 10^4 Btu/hr/lb of uranium. The long-term storage of these highly radioactive fission products are a serious problem. They are determined by long-lived isotopes, i.e., strontium 90, which has a 28-year half-life, and cesium 137, which has a 30-year half-life (Reference 7). The following procedures are presently used in the handling and disposing of these wastes.

- Wastes are removed from the reactor in shielded containers designed to withstand shipping accidents.
- Containers are cut open at reprocessing plants; the contents are dissolved in acid, and uranium and plutonium recovered. Radioactive fission products are concentrated and stored in double walled containers for 5 years.
- After 5 years, products are evaporated to dryness, sealed in steel containers, and shipped to the national waste repository in central Kansas for storage at a depth of 1500 feet for a period of a thousand years.

The shipping and processing techniques have been developed and proved safe. All nuclear powerplants are monitored by the United States Public Health Service for radioactivity, and the disposal of solid wastes follows a strictly regulated and monitored procedure.

The future of the radioactive waste problem depends on the advancement of reactor technology. The light-water reactors used now have two disadvantages: (1) low thermal efficiency, and (2) requirement for uranium-235 which is scarse. By 1980, these reactors would require 200,000 tons of uranium concentrate, and 1.6 million tons in the year 2000.

This could exhaust our estimate of this low-cost uranium. The breeder reactor would use the more abundant U-238. The breeder reactor would require 1.3 tons uranium per Mkwh compared to 171 tons for the light-water reactor, and would increase the conversion efficiency of nuclear power conversion to that now enjoyed by fossil fuels (Reference 8).

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In addition to this specifically referenced material, much reliance has been placed on:

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APPENDIX B

CURRENT LISTINGS OF HAZARDOUS MATERIALS

The definition of hazardous materials is an elusive quest. Under certain conditions, distilled water may be hazardous (drowning). Any listing of hazardous materials is an effort to select and list those materials of particular impact on the mission of the interested organization. On the assumption that a comparison of materials on the various lists would provide insights as to those hazardous materials of most widespread concern, we have prepared a tabulation which indicates the materials contained on each list.

The listings identified by the numbers (column headings) are from:

(1) Designation of Hazardous Substances (draft EPA-WQO list)

(2) Control of Spillage of Hazardous Polluting Substances - Battelle

(3) Dangerous Chemicals Code - Los Angeles Fire Department

(4) Manufacturing Chemists Association

(5) National Institute of Occupational Safety and Health

(6) National Academy of Sceinces

(7) Chemical Safety References - Chemical Section, National Safety Council.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ABIETIC ACID	X	X					
ACETALDEHYDE	X	X	X	X	X	X	X
ACETALDOL	X	X					
ACETAMIDE	X	X					
ACETANILIDE	X		X				
ACETIC ACID	X	X	X	X	X	X	X
ACETIC ANHYDRIDE	X	X	X	X	X	X	X
ACETONE		X	X	X	X	X	X
ACETONE CYANHYDRIN	X	X	X	X		X	X
ACETONITRILE	X	X	X	X	X	X	X
ACETOPHENONE		X	X				
ACETYL BENZOYL PEROXIDE		X	X				
ACETYL BROMIDE	X		X				
ACETYL CHLORIDE		X	X	X			
ACETYLENE	X		X				X
ACETYLENE CHLORIDE		X	X				
ACETYLENE DICHLORIDE	X	X			X		
ACETYL PEROXIDE, WET SOLID		X	X	X			
ACRIDINE	X	X		X			
ACROLEIN		X	X	X	X	X	X
ACRYLIC ACID	X	X	X	X		X	
ACRYLONITRILE	X	X	X	X	X	X	X
ADIPIC ACID	X	X	X				X
ADIPONITRILE		X		X		X	X
ALANINE	X	X					
ALKYL ARYL SULFONATE	X	X					

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ALLYL ACETATE	x	x		x			
ALLYL ALCOHOL	x	x	x	x	x	x	x
ALLYL AMINE	x	x		x			
ALLYL BROMIDE		x	x	x			
ALLYL CHLORIDE	x	x	x	x	x	x	x
ALLYL CHLOROFORMATE (see allyl) CHLOROCARBONATE		x	x	x			
ALLYL TRICHLORISLIANE	x	x					
ALLYLDINE DIACETATE	x	x					
ALUMINUM AMMONIUM SULFATE	x	x					
ALUMINUM, DUST			x	x			
ALUMINUM CHLORIDE, ANHYDROUS		x	x	x			
ALUMINUM FLUORIDE		x					
ALUMINUM NITRATE		x	x	x			
ALUMINUM OXIDE	x	x					
ALUMINUM SULFATE	x	x					
ALUMINUM TRIETHYL	x	x	x				
AMINOETHYLETHANOLAMINE	x	x	x	x		x	x
4-AMINO-M-TOLUENE	x	x					
AMMONIA, AQUA (ammonium hydroxide)	x	x	x	x	x	x	x
AMMONIUM ACETATE	x	x					
AMMONIUM ARSENATE		x	x				
AMMONIUM CARBONATE	x	x					
AMMONIUM CHLORIDE	x	x					
AMMONIUM CHROMATE	x	x	x				
AMMONIUM DICHROMATE	x	x		x			x
AMMONIUM FERRO-CYANIDE	x	x					
AMMONIUM FLUORIDE		x	x	x			

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
AMMONIUM HYDROXIDE (see Ammonia, aqua)							
AMMONIUM MOLYBDATE	x	x					
AMMONIUM NITRATE	x	x	x	x			x
AMMONIUM PERCHLORATE	x	x	x	x			
AMMONIUM PERMANGANATE		x	x				
AMMONIUM PERSULPHATE		x	x	x			
AMMONIUM PICRATE, DRY	x	x	x				
AMMONIUM PICRATE, WET	x	x	x				
AMMONIUM SULFATE	x	x					
AMMONIUM SULFIDE	x	x		x			
AMMONIUM SULFITE	x	x					
AMMONIUM THIOCYANATE	x	x					
AMYL ACETATE (BANANA OIL)	x	x	x	x	x	x	x
AMYL ALCOHOL (FUSEL OIL)		x	x	x		x	x
AMYL ALCOHOL, PRIM. -ISO (Butyl carbinol)	x	x	x				
AMYL ALCOHOL, s, -n	x	x	x				
AMYL ALCOHOL, s. -iso.	x	x	x				
AMYL ALCOHOL, ter.	x	x	x				
AMYLAMINE		x	x	x			
AMYLAMINE, sec. -mono		x	x				
AMYLAMINE LAURATE		x	x				
AMYLAMINE OLEATE		x	x				
ANYLAMINE STEARATE		x	x				
AMYL BROMIDE	x	x		x			
AMYL MERCAPTAN		x	x	x			
AMYL NITRITE (ISOAMYL NITRATE)		x	x				
AMYL TRICHLOROSILANE PENTANE	x	x					
ANILINE, OIL (AMINOBENZENE)	x	x	x	x	x	x	x

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ANILINE HYDROCHLORIDE		X	X				
ANISOYL CHLORIDE		X	X				
ANTHRACENE		X	X				
ANTIMONY PENTACHLORIDE	X	X	X	X			X
ANTIMONY PENTAFLUORIDE	X	X	X				X
ANTIMONY PENTASULFIDE	X	X	X	X			X
ANTIMONY POTASSIUM TARTRATE	X	X					X
ANTIMONY, POWDERED	X		X				X
ANTIMONY SULFATE	X		X				X
ANTIMONY SULFIDE	X		X				X
ANTIMONY TRICHLORIDE	X	X		X			X
ANTIMONY TRIETHYL (TRIETHYLSTIBINE)	X		X				X
ANTIMONY TRIFLUORIDE	X	X					X
ANTIMONY TRIMETHYL (TRIMETHYLSTIBINE)	X		X				X
ANTIMONY TRIOXIDE	X	X		X			X
ARGON			X				
ARSENIC CHLORIDE	X	X	X				X
ARSENIC DIETHYL	X	X	X				X
ARSENIC DIMETHYL	X	X	X				X
ARSENIC TRICHLORIDE	X	X	X	X			X
BARIUM ACETATE	X	X					X
BARIUM CARBIDE		X	X				X
BARIUM CARBONATE		X					X
BARIUM CHLORIDE	X	X	X	X			X
BARIUM CYANIDE	X	X	X				X
BARIUM FLUORIDE	X	X					X
BARIUM NITRATE	X	X	X				X
BARIUM PERCHLORATE		X	X				X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BARIUM PERMANGANATE		x	x				x
BARIUM PEROXIDE		x	x				x
BARIUM SULFIDE		x	x				x
BENZALDEHYDE		x	x	x			
BENZENE (BENZOL)	x	x	x	x	x	x	x
BENZENE SULFONIC ACID	x	x		x			
BENZINE PHOSPHOROUS DICHLORIDE	x	x					
BENZOIC ACID	x	x	x				
BENZONITRILE	x	x		x			
BENZOYL CHLORIDE	x	x	x	x			
BENZYL ALCOHOL (PHENYL CARBINOL)		x	x	x			
BENZYLAMINE	x	x		x			
BENZYL BROMIDE (BROMOTOLUENE)		x	x	x			
BENZYL CHLORIDE		x	x	x	x		x
BENZYL CHLOROFORMATE		x	x	x			
BERYLLIUM, POWDER	x	x	x	x	x		x
BLEACHING POWDER (see calcium hypochlorite)			x				x
BORIC ACID	x	x		x			
BORON HYDRIDE	x	x	x				
BORON TRICHLORIDE, IN CYL.	x	x	x	x			x
BORON TRIETHYL	x		x				x
BORON TRIFLUORIDE	x	x	x	x	x		x
BORON TRIMETHYL	x		x				x
BROMACETONE	x	x	x				
BROMINE	x	x	x	x	x		x
BROMINE PENTAFLUORIDE		x	x	x	x		x
BROMINE TRIFLUORIDE		x	x	x			
BROMOBENZYL CYANIDE	x	x	x				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BROMOETHANE (see ethyl bromide)		X	X	X			
BROMOMETHANE (see methyl bromide)		X	X				
BUTADIENE (ERYTHRENE), IN CYL.		X	X	X	X	X	X
IN DRUMS		X	X				
BUTANE-n (BUTYL HYDRIDE)		X	X			X	
BUTANE-iso (2 METHYLPROPANE)		X	X				
BUTANOL (see butyl alcohol)		X	X				
BUTENE-1 (ETHYL ETHYLENE)		X	X				
BUTYL ACETATE-n (BUTYL ETHANOATE)	X	X	X		X	X	X
BUTYL ACETATE-iso	X	X	X				
BUTYL ACETATE-sec. (2-BUTANOL ACETATE)	X	X	X		X	X	
BUTYL ACRYLATE	X	X				X	
BUTYL ALCOHOL-n	X	X	X		X	X	X
BUTYL ALCOHOL-iso	X	X	X			X	X
BUTYL ALCOHOL-sec	X	X	X		X	X	X
BUTYL ALCOHOL-tert	X	X	X		X	X	X
BUTYL ALDEHYDE-n (BUTYRALDEHYDE)		X	X			X	
BUTYLAMINE-n	X	X	X	X	X		X
BUTYLAMINE-sec, mono	X	X	X				
BUTYLAMINE-iso	X	X	X	X			
BUTYLAMINE OLEATE-mono	X	X	X				
BUTYLENE GLYCOL	X		X				X
BUTYL HYDROPEROXIDE-tert		X	X				
BUTYL LITHIUM	X	X					
BUTYL MERCAPTAN	X	X		X	X		X
BUTYL PROPIONATE (BUTYL PROPANOATE)		X	X				
BUTYRALDEHYDE (BUTYL ALDEHYDE-n)		X	X	X		X	X
BUTYRIC ACID-n		X	X	X		X	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CADMIUM, POWDERED	X		X	X			X
CADMIUM BROMATE	X		X				X
CADMIUM CHLORATE	X		X				X
CADMIUM CHLORIDE	X	X		X			X
CADMIUM NITRATE	X	X	X				X
CADMIUM OXIDE				X	X		X
CADMIUM PICRATE	X		X				X
CADMIUM SULFATE	X	X					X
CALCIUM		X	X				
CALCIUM ARSENATE		X	X	X	X		X
CALCIUM CARBIDE	X	X	X				X
CALCIUM CHLORIDE	X	X	X	X			
CALCIUM CYANIDE	X	X	X	X			
CALCIUM FLUORIDE	X	X					X
CALCIUM FLUOROSILICATE	X	X					
CALCIUM HYDRIDE (HYDROLITH)	X	X	X	X			
CALCIUM HYDROXIDE		X		X			
CALCIUM HYPOCHLORITE	X	X	X	X			
CALCIUM HYPOPHOSPHITE	X	X	X				
CALCIUM NITRATE		X	X				
CALCIUM PHOSPHATE	X						
CALCIUM PHOSPHIDE (PHOTOPHOR)	X		X				
CALCIUM SULFATE	X	X					
CAMPHOR		X	X	X	X	X	X
CARBON BISULFIDE (OR DISULFIDE)	X	X	X	X	X	X	X
CARBON DIOXIDE			X		X		X
CARBON MONOXIDE	X	X	X	X	X		X
CARBON TETRACHLORIDE	X	X	X	X	X	X	X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CAUSTIC POTASH (see POTASSIUM HYDROXIDE)		X	X	X		X	X
CAUSTIC SODA (see sodium hydroxide)		X	X	X		X	X
CETYL ALCOHOL (HEXADECANOL) INSOL	X	X					
CHARCOAL, ACTIVATED			X				
CHENOPODIUM OIL	X	X					
CHLORAMINE-t	X	X					
CHLORINE	X	X	X	X	X	X	X
CHLORINE TRIFLUORIDE		X	X	X	X		X
CHLOROBENZENE (see chlorobenzol)	X	X	X	X	X	X	X
CHLOROBUTADIENE	X			X	X		
CHLOROFORM (TRICHLOROMETHANE)	X	X	X	X	X	X	X
CHLOROHYDRIN	X	X				X	X
CHLOROISOCYANURIC ACID	X	X					
CHLOROMETHANE (see methyl chloride)		X	X				
CHLOROPHENOL ORTHO, LIQ.		X	X	X			
3-CHLOROPROPENE (see allyl chloride)		X	X				
CHLOROSULFONIC ACID	X	X	X	X		X	X
CHROMIC ACID, LIQUID	X	X	X		X		X
SOLID	X	X	X				
CHROMIC ANHYDRIDE	X		X				
CHROMIUM PICRATE	X		X				X
CHROMIUM TRIOXIDE							X
CHROMYL CHLORIDE		X		X			
CITRIC ACID	X	X					
COBALT CHLORIDE	X	X					X
COBALT NITRATE	X	X	X	X			X
COBALT SULFATE	X	X					X
COBALTOUS NITRATE		X	X	X			X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
COPPER ACETOARSENITE	X	X					X
COPPER ACETYLENE	X		X				X
COPPER ACETYLIDE	X		X				X
COPPER CHLORATE	X		X				X
COPPER CHLORIDE	X	X					X
COPPER CYANIDE	X		X				X
COPPER NITRATE	X	X	X	X			X
COPPER PICRATE	X		X				X
COPPER PROPARGYLATE	X		X				X
COPPER SULFATE	X	X					X
COPPER TETRAZOL	X		X				X
CRESOL (CRESYLIC ACID)	X	X	X	X	X	X	X
CRESOTIC ACID	X	X					X
CROTONALDEHYDE	X	X	X	X	X	X	X
CUMENE (ISOPROPYLBENZOL)		X	X		X	X	X
CUMENE HYDROPEROXIDE		X	X				
CUPRIC ACETATECUPRIC CHROME GLUCONATE	X	X					
CUPRIC OXIDE	X	X					
CUPRIC SULFATE							
CYANOGEN BROMIDE	X		X				X
CYANOGEN CHLORIDE	X	X	X	X			
CYANAMIDE	X		X	X			
CYCLOHEXANE (HEXAHYDROBENZENE)	X	X	X		X	X	X
CYCLOHEXANE CARBOXYLIC ACID	X						X
CYCLOHEXANOL (HEXALIN)		X	X		X	X	X
CYCLOHEXANONE		X	X		X	X	X
CYCLOHEXYLAMINE		X	X	X			
DECARBORANE	X	X		X	X		

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DECALDEHYDE	X	X					
DECENE		X					
DECYL ALCOHOL		X				X	
DENATURED ALCOHOL (see methyl alcohol)			X				
DETERGENTS	X	X					
DIALLYL PHTHALATE		X	X				
DIAMINOETHANE	X		X		X		
DIAMYLAMINE		X	X				
DIBORANE		X	X	X	X		
DIBUTYL PEROXIDE	X	X		X			
DIBUTYL PHTHALATE-n	X	X	X			X	X
DIBUTYL THIOUREA	X	X					
DICHLORETHYLENE (ETHYLENE DICHLORIDE)			X	X	X		
DICHLOROBENZENE-o	X	X	X	X	X	X	X
DICHLOROBENZENE-p	X	X	X		X		
2, 3-DICHLOROBUTANE		X	X				
DICHLRORDIFLUOROMETHANE (FREON 12)		X	X		X	X	X
DICHLOROETHYLENE-1, 2 (acetylene dichloride)	X	X	X		X		
DICHLOROETHYLENE-1, 1 (vinylidene chloride)		X	X		X		X
DICHLRORETHYL ETHER		X	X	X	X	X	X
DICHLRORISOPROPYL ETHER		X	X				
DICHLOROMETHANE (see(methylene chloride)	X		X	X	X		
DICHLOROPHENOL	X	X					
2-DICHLOROPROPANE	X	X					
1, 3-DICHLOROPROPENE		X	X	X		X	X
2-DICHLOROPRO			X		X		X
DICHLOROTETRAFLUORETHANE (F-114)			X		X		X
DICYCLOPENTADIENE		X		X	X	X	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DIMETHYL HYDRAZINE	X	X			X		X
DIETHANOLAMINE	X	X	X			X	X
DIETHYL ALUMINUM CHLORIDE	X	X		X			
DIETHYLAMINE	X	X	X	X	X	X	X
DIETHYL BENZENE		X	X			X	X
DIETHYLDICHLRORSILANE		X	X				
DIETHYLENE GLYCOL		X	X			X	X
DIETHYLENE GLYCOL MONOETHYL ETHER		X	X			X	
DIETHYLENE TRIAMINE		X	X		X	X	X
DIETHYL PHTHLATE	X		X	X			
DIISOBUTYLENE		X	X			X	X
DIISOBUTYL KETONE		X	X		X	X	X
DIISOPROPANOLAMINE	X	X	X		X	X	X
DIISOPROPYLAMINE	X	X	X		X		
DIISOPROPYL PEROXI DICARBONATE	X	X					
DIMETHYLAMINE, IN CYL. 25% SOLN.	X	X	X	X	X	X	
DIMETHYL DIOXANE		X	X				
DIMETHYL ETHER (methyl ether) DRUM		X	X				X
DIMETHYL FORMAMIDE (DMF)		X	X		X		X
DIMETHYL SULFATE (METHYL SULFATE)	X	X	X	X	X		X
DIMETHYL SULIDE (METHYL SULFIDE)		X	X	X			
DIMETHYL SUFORIDE	X			X			
DINITROANILINE-2, 4		X	X	X			
DINITROBENZOL (DINITROBENZENE)	X	X	X		X		X
DINITRO CRESOLS	X	X		X	X		X
DINITROPHENOL	X	X	X	X			X
DINITROTOLUENE (DINITROTOLUOL)		X	X	X	X		X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DIOXANE		X	X	X	X		X
DIPFNTENT (CINENE)	X	X	X				
DIPHENYLAMINE (phenylaniline)		X	X	X	X		X
DIPROPYLENE GLYCOL		X	X			X	X
DIVINYLBENZENE (Vinylstyrene)		X	X				
DODECANOL		X					
DODECENE		X					
DODECYL BENZENE, CRUDE		X	X			X	
DODECYL MERCAPTAN (see Lauryl mercaptan)		X	X				
DYES	X	X					
EPICHLOROHYDRIN	X	X		X	X	X	X
ETHANOLAMINE	X		X	X	X		X
ETHERS	X	X					
ETHOXY TRIGLYCOL		X				X	
ETHYL ACETATE (ACETIC ETHER)		X	X		X	X	X
ETHYL ACRYLATE-MONOMER	X	X	X	X	X	X	
ETHYL ALCOHOL (ETHANOL)	X	X	X		X	X	X
ETHYLAMINE (MONOETHYLAMINE)	X	X	X	X	X		X
ETHYL BENZENE (PHENYL ETHANE)	X	X	X	X	X	X	X
ETHYL CHLORIDE (chloroethane), in cyl.		X	X	X	X	X	X
ETHYLENE (ETHENE)	X	X	X			X	X
ETHYLENE CYANOHYDRIN		X	X			X	X
ETHYLENE DICHLORIDE (DICHLORETHYLENE)		X	X	X	X	X	X
ETHYLENE GLYCOL (GLYCOL)	X	X	X			X	X
ETHYLENE GLYCOL MONOBUTYL ETHER	X			X		X	X
ETHYLENE GLYCOL MONOETHYL ETHER		X	X		X	X	X
ETHYLENE GLYCOL MONOETHYL ETHER ACETATE		X	X			X	X
ETHYLENE OXIDE, IN CYL. IN DRUMS		X	X	X		X	X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ETHYLENIMINE	x	x			x	x	x
ETHYLHEXANOL (OCTYL ALCOHOL)		x	x	x		x	x
2-ETHYLHEXYL ACRYLATE		x				x	
ETHYL METHYL KETONE		x	x				
ETHYL PHTHALATE	x	x					
2-ETHYL-3 PROPYLACROLEIN		x	x	x		x	x
FATTY ACIDS	x	x				x	
FERRIC CHLORIDE	x	x					
FERRIC OXIDE	x	x					
FERRIC POTASSIUM SULFATE	x	x					
FERRIC SULFATE	x	x					
FERROSILICON			x				
FERROUS CHLORIDE	x	x					
FERROUS OXIDE	x	x					
FERROUS SULFATE	x	x					
FERROUS SULFIDE	x	x					
FERROUS SULFITE	x	x					
FLUORINE	x	x		x	x		x
FLUOSULFONIC ACID		x	x				
FORMALDEHYDE, 37% solution	x	x	x	x	x	x	x
FORMIC ACID		x	x	x	x	x	x
FUMARIC ACID	x	x					
FURFURAL (Furfuraldehyde)	x	x	x		x	x	x
FURFURYL ALCOHOL	x	x	x		x	x	x
GALLIC ACID	x	x		x			
GASOLINE			x			x	x
GLYCERINE (GLYCEROL)	x	x	x	x		x	x
GLYCOL DIACETATE (DIACETIN)		x	x			x	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GLYOXAL		X		X		X	
GUAIACOL	X	X		X			
HAFNIUM	X	X			X		X
HELIUM			X				
n-HEPTANE (Heptyl hydride)		X	X		X	X	X
HEPTANOL	X	X	X				
1-HEPTENE	X	X	X			X	
HEXAETHYL TETRAPHOSPHATE		X					
HEXAFLUOROPHOSPHORIC ACID		X	X				
HEXAFLUOROPROPYLENE	X	X					
HEXAMETHYLENE DIAMINE	X	X	X				
HEXANE (Hexyl hydride)		X	X		X	X	X
iso-HEXANE	X	X	X				
HEXANOL (Hexyl alcohol-n)	X	X	X				
HEXYLENE GLYCOL		X	X			X	X
HEXYL TRICHLOROSILANE	X	X					
HYDRAZINE (ANHYDROUS DIAMINE)	X	X	X	X	X		X
HYDROCHLORIC ACID (MURIATIC ACID)	X	X	X	X		X	X
HYDROCYANIC ACID	X		X	X			X
HYDROFLUORIC ACID	X	X	X	X		X	X
HYDROFLUOSILICIC ACID		X	X				
HYDROGEN		X	X				X
HYDROGEN BROMIDE, ANHYDROUS		X	X		X		X
HYDROGEN CHLORIDE, ANHYDROUS		X	X		X	X	X
HYDROGEN CYANIDE (see hydrocyanic acid)		X	X		X		X
HYDROGEN PEROXIDE - OVER 52%	X	X	X	X	X		X
HYDROGEN SULFIDE		X	X	X	X		X
HYDROQUINONE	X	X	X	X	X		X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
HYDROXYLAMINE (OXAMMONIUM)	x	x	x	x			
HYPOCHLORITE	x	x					
HYPOIODITE	x	x					
IODACETIC ACID	x	x					
IODINE, TINCTURE OF		x	x	x	x		x
IODINE MONOCHLORIDE	x	x					
ISOBUTENE (2-Methyl propene)		x	x				
ISOBUTYL ACETATE		x	x		x	x	x
ISOBUTYRALDEHYDE (Isobutyl aldehyde)		x	x			x	x
ISODECALDEHYDE		x				x	x
ISODECANOL		x				x	
ISOOCTANE		x	x			x	x
ISOOCTENE		x	x				
ISOOCTYL ALDEHYDE		x				x	x
ISOPENTANE		x	x				
ISOPHORONE	x	x	x			x	x
ISOPRENE	x	x	x	x		x	x
ISOPROPYL ACETATE		x	x		x	x	x
ISOPROPYL ALCOHOL (Isopropanol)		x	x		x	x	x
ISOPROPYL AMINE		x	x		x		x
ISOPROPYL ETHER		x	x		x	x	x
ISOPROPYL FORMATE		x	x				
ISOPROPYL MERCAPTAN	x	x					
LACTIC ACID	x	x					
LACTONITRILE		x	x	x			
LAURYL CHLORIDE (dodecyl chloride)		x	x				
LEAD ACETATE	x	x	x	x			x

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
LEAD ARSENATE	X	X	X	X	X		X
LEAD ARSENITE	X	X	X				X
LEAD CHLORIDE	X	X					X
LEAD CHLORITE	X	X	X				X
LEAD CYANIDE	X	X	X				X
LEAD NITRATE	X	X	X				X
LEAD NITRITE	X	X	X				X
LEAD PEROXIDE (LEAD OXIDE)			X				X
LEAD SULFATE	X	X					X
LEAD SULFOCYANATE		X					X
LEAD TETRAMETHYL	X		X				X
LITHIUM CARBONATE	X	X					
LITHIUM CHLORIDE	X	X					
LITHIUM FERRO SILLICON	X	X					
LITHIUM FLUORIDE	X	X					
LITHIUM HYDROXIDE	X	X			X		
LITHIUM HYPOCHLORITE	X	X					
LITHIUM SULFATE		X					
MAGNESIUM ARSENATE	X	X					
MAGNESIUM CHLORIDE	X	X					
MAGNESIUM, DAMP POWDER Powder, ribbon or chips		X	X				X
MAGNESIUM FLUORIDE	X	X					
MAGNESIUM NITRATE	X	X					
MAGNESIUM PERCHLORATE		X	X				
MAGNESIUM PEROXIDE		X	X				
MAGNESIUM SILICO-FLUORIDE	X	X					
MAGNESIUM SULFATE		X					
MAL[illegible]C ACID	X	X		X			

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)
MALEIC ANHYDRIDE	X	X	X	X	X		X
MANGANESE CHLORIDE	X	X					X
MANGANESE NITRATE	X	X					X
MANGANESE SULFATE	X	X					X
MERCAPTANS (DODECYL)	X	X					
MERCAPTOETHANOL		X	X	X			
MERCURIC AMMONIUM CHLORIDE		X					
MERCURIC BENZOATE		X					
MERCURIC BROMIDE		X					
MERCURIC CHLORIDE		X		X			
MERCURIC CYANIDE		X					
MERCURIC IODINE		X					
MERCURIC NITRATE	X	X	X				
MERCURIC OLEATE		X					
MERCURIC OXIDE		X					
MERCURIC OXYCYANIDE	X	X	X				
MERCURIC POTASSIUM CYANIDE		X					
MERCURIC SALICYLATE		X					
MERCURIC SULFATE AND SUBSULFATE		X					
MERCURIC SULFOCYANATE		X					
MERCUROUS BROMIDE		X					
MERCUROUS CHLORIDE		X					
MERCUROUS GLUCONATE		X					
MERCUROUS IODIDE		X					
MERCUROUS NITRATE	X	X	X				
MERCUROUS SULFATE		X					
MERCURY	X	X		X	X	X	
MERCURY ACETATEMESITYLENE		X					

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
MESITYL OXIDE		X	X	X		X	X
METHANE (MENTHYL HYDRIDE)		X	X		X	X	X
METHANOL (see methyl alcohol)	X	X	X		X	X	X
METHYL ACETATE	X	X	X	—	X	X	X
METHYL ACETYLENE	X	X					X
METHYL ACRYLATE (ACRYLIC ESTERS)	X	X	X	X	X	X	
METHYL ALCOHOL (METHANOL)	X	X	X		X	X	X
METHYLAMINE, 30% solution gas	X	X	X		X		X
METHYL AMYL ACETATE		X	X			X	
METHYL AMYL ALCOHOL		X	X	X	X	X	X
METHYL BROMIDE (BROMOMETHANE)	X	X	X	X	X	X	X
METHYL BUTYRALDEHYDE		X				X	
METHYL CHLORIDE (CHLOROMETHANE)		X	X	X	X	X	X
METHYL CHLOROFORMATE	X	X	X	X			X
METHYLENE CHLORIDE (CARRENE)		X	X		X	X	
METHYL DICHLOROSILENE	X	X					
METHYL ETHER (DIMETHYL ETHER)		X	X	X			
METHYL ETHYL ETHER (see ethyl methyl ether)			X				
2-METHYL, 5-ETHYL PYRIDINE	X	X				X	
METHYL FORMATE		X	X	X	X	X	X
METHYL HYDRAZINE	X	X					X
METHYL ISOBUTYL CARBINOL		X	X		X		
METHYL ISOBUTYL KETONE (HEXONE)	X	X	X	X	X	X	X
METHYL MERCAPTAN (METHANETHIOL)	X	X	X	X	X		X
METHYL METHACRYLATE MONOMER	X	X	X		X	X	
METHYLNAPHTHOQUINONE	X	X					
METHYL SALICYLATE		X	X				
MINERAL SPIRITS		X	X			X	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
MONOBROMOTRIAUOROMETHANE							
MONOBROMO TRICHLOROETHER	X	X					
MONOCHLOROACETIC ACID	X	X					
MONOCHLOROACETONE (SEE CHLOROACETONE)	X	X	X				
MONOCHLORODIFLUOROMETHANE (FREON 22)		X	X			X	X
MONOCHLOROFLUOROETHANE	X	X					
MONOETHANOLAMINE (see ethanolamine)		X	X	X		X	
MONOETHYLAMINE (see ethylamine)	X	X	X	X			
MONOFLUOROPHOSPHORIC ACID, ANHYD.		X	X				
MONOISOPROPANOLAMINE		X	X			X	
MONOMETHYL HYDRAZINE	X	X					
MORPHOLINE		X	X	X	X	X	X
MOTOR FUEL ANTI-KNOCK COMPOUND	X	X		X			
NAPHTHA			X	X	X		X
NAPHTHALENE (NAPHTHALINE)	X	X	X	X	X	X	X
NAPHTHALIC ACID	X	X					
NAPHTHOL-beta	X	X	X				
NAPHTHOQUINONE	X	X					
NAPHTHYLAMINE-beta	X	X	X	X			X
NICKEL AMMONIUM SULFATE	X	X					X
NICKEL CARBONYL	X	X	X	X	X		X
NICKEL CHLORIDE	X	X					X
NICKEL CYANIDE	X	X	X				X
NICKEL NITRATE	X	X	X				X
NICKEL SULFATE	X	X					X
NICOTINE HYDROCHLORIDE		X					X
NICOTINE SALICYLATE TARTATE AND SULFATE		X					X
NITRATING ACID		X	X				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NITRIC ACID	X	X	X	X	X	X	X
NITROANILINE (see nitraniline-meta, para)	X	X	X	X	X		X
NITROBENZENE (NITROBENZOL)	X	X	X	X	X		X
NITROCHLOROBENZENE, meta or para	X	X	X		X		X
NITROETHANE	X	X	X		X		X
NITROGEN	X	X	X				
NITROHYDROCHLORIC ACID (see aqua regia)		X	X				
NITROMETHANE		X	X		X		X
NITROPHENOL	X	X		X			
1-NITROPROPANE	X	X	X		X	X	X
NITROSYL CHLORIDE (see Nitrogen oxychloride)		X	X	X			
p-NITROTOLUOL (nitrotoluene)		X	X	X	X		X
NITROUS OXIDE		X	X			X	X
n-NONANE (Nonyl hydride)		X	X			X	
NONTHENE		X					
NONYL ALCOHOL	X	X				X	
NONYLPHENOL		X	X	X		X	X
OCTODECYL TRICHLOROSILANE	X	X					
OCTYL ALCOHOL-n (2-Ethylhexyl alcohol)	X	X	X				
OCTYL TRICHLOROSILANE	X	X					
OIL OF VITRIOL (see sulfuric acid)		X	X				
OLEIC ACID (RED OIL)	X	X	X			X	X
OLEUM (Hi-strength sulfuric acid)		X	X				
ORTHO-NITROANILINE	X	X					
OXALIC ACID	X	X		X	X		
OXYDIPROPIONITRILE	X	X					
OXYGEN		X	X	X			X
OXYGEN DIFLUORIDE	X	X					

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PARAFORMALDEHYDE	X	X	X	X			X
PARALDEHYDE (Paracetaldehyde)		X	X	X			
PENTABORANE, in drums		X	X	X	X		
n-PENTANE (AMYL HYDRIDE)	X	X	X		X	X	
PENTANOL	X			X			
PENTENE (AMYLENE)	X		X	X			
PERACETIC ACID		X	X	X			
PERCHLORIC ACID - to 72% strength		X	X	X			X
PERCHLOROETHYLENE		X				X	X
PERCHLORO-METHYL-MERCAPTAN		X		X	X		X
PERCHLORYL FLUORIDE	X	X		X	X		X
PETROLEUM ETHER (See benzine)		X	X			X	
PHENANTHRENE	X	X					
PHENOL (see carbolic acid)	X	X	X	X	X	X	X
PHENYCARBYLAMINE CHLORIDE	X	X	X				
PHENYLETHANOLAMINE		X	X	X			
PHENYLTRICHLOROSILANE		X	X				
PHOSGENE	X			X	X		X
PHOSPHINE (phosphoretted hydrogen)		X	X		X		X
PHOSPHORIC ACID	X	X		X	X	X	X
PHOSPHORIC ANHYDRIDE		X	X	X			X
PHOSPHORUS, RED	X	X	X			X	X
PHOSPHORUS, WHITE OR YELLOW	X	X	X	X	X	X	X
PHOSPHORUS OXYBROMIDE	X	X					
PHOSPHORUS OXYCHLORIDE	X	X		X			X
PHOSPHORUS PENTACHLORIDE		X	X	X	X		X
PHOSPHORUS PENTASULFIDE	X	X	X	X	X		X
PHOSPHORUS SESQUISULFIDE		X	X	X			

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PHOSPHORUS TRIBROMIDE		X	X				
PHOSPHORUS TRICHLORIDE	X	X	X	X			X
PHTHALIC ANHYDRIDE		X	X	X	X		X
PICRIC ACID (TRINITROPHENOL), liquid		X	X	X	X		X
POLYPROPYLENE GLYCOL METHYL ETHER	X	X					
POLYVINYL ALCOHOL							
POTASSIUM	X	X	X	X			
POTASSIUM ACETATE	X	X					
POTASSIUM AMMONIUM NITRATE		X	X				
POTASSIUM ARSENITE, SOLID		X	X				
POTASSIUM BIFLUORIDE		X	X				
POTASSIUM BROMATE		X	X				
POTASSIUM CARBONATE							
POTASSIUM CHLORATE		X	X				
POTASSIUM CHLORIDE	X	X					
POTASSIUM CHROMATE	X	X	X				
POTASSIUM CUPRIC	X	X					
POTASSIUM CYANIDE, SOLID	X	X	X	X			
POTASSIUM DICHLOROISOCYANURATE	X	X					
POTASSIUM DICHROMATE	X	X	X	X			
POTASSIUM FERRICYANIDE		X	X				
POTASSIUM FERROCYANIDE							
POTASSIUM FLUORIDE	X	X		X			
POTASSIUM HYDROXIDE, SOLID	X	X	X				
POTASSIUM IODIDE		X					
POTASSIUM NITRATE, SOLID		X	X				
POTASSIUM NITRITE, SOLID		X	X				
POTASSIUM PERCHLORATE		X	X				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
POTASSIUM PERMANGANATE	x	x	x				
POTASSIUM PEROXIDE		x	x	x			
POTASSIUM PERSULFATE		x	x				
POTASSIUM PHOSPHATE	x	x					
POTASSIUM SILICOFLUORIDE	x	x					
POTASSIUM SULFATE		x					
POTASSIUM SULFIDE	x	x		x			
POTASSIUM THIOCYANATE	x	x					
PROPANE (see also L. P. Gas)	x	x	x			x	
PROPANOLAMINE	x		x				
PROPIOLACTONE-beta		x	x			x	x
PROPIONALDEHYDE		x	x	x		x	x
PROPIONIC ACID	x	x		x		x	x
PROPIONIC ANHYDRIDE	x	x	x			x	
PROPYL ACETATE-n		x	x		x	x	x
PROPYL ALCOHOL-n	x	x	x		x	x	x
PROPYL AMINE, mono-n	x	x	x	x			
PROPYLENE		x	x			x	x
PROPYLENE BUTYLENE POLYMER	x	x					
PROPYLENE GLYCOL		x	x			x	x
PROPYLENE IMINE	x	x		x			x
PROPYLENE OXIDE	x	x			x	x	x
PROPYLENE TETRAMER	x	x					
PROPYL MERCAPTAN	x	x					
PROPYL NITRATE-n		x	x	x			x
PROPYL TRICHLOROSILANE	x	x					
PYRIDAL MERCURIC ACETATE	x	x					
PYRIDINE							

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
PYROCATECHOL	X	X	X					
PYROGALLOL	X	X						
PYRO SULFURYL CHLORIDE		X	X					
PYROXYLIN, SOLID (see cellulose nitrate)		X	X					
QUINOLINE	X	X		X				
QUINONE	X	X		X	X		X	
RESIN (ROSIN, COLOPHONY)		X	X				X	
RESORCINAL (Dihydroxy benzene-m)	X	X	X	X				
SALICYLALDEHYDE	X			X				
SALICYLIC ACID	X	X	X	X				
SAPONINS	X	X						
SELENIUM, POWDER	X	X	X	X	X		X	
SILICON CHLORIDE		X	X					
SILICON TETRAFLUORIDE	X	X		X				
SILVER CHLORIDE							X	
SILVER CYANIDE (see cyanide of silver)	X	X	X				X	
SILVER NITRATE	X	X	X				X	
SODIUM	X	X	X	X			X	
SODIUM ACETATE		X	X					
SODIUM ALUMINATE	X	X						
SODIUM ALUMINUM HYDRIDE	X	X						
SODIUM AMIDE (SODAMIDE)		X	X	X				
SODIUM ARSENATE	X	X						
SODIUM ARSENITE	X	X						
SODIUM AZIDE	X	X	X	X				
SODIUM BICARBONATE	X	X						
SODIUM BIFLUORIDE	X	X						
SODIUM BISULFATE	X	X		X				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
SODIUM BISULFITE	X	X						
SODIUM BORATE	X	X						
SODIUM BROMATE		X	X					
SODIUM BUTYL MERCAPTIDE	X	X						
SODIUM CARBONATE PEROXIDE	X	X	X	X				
SODIUM CHLORATE		X	X					
SODIUM CHLORIDE	X	X						
SODIUM CHLORITE		X	X					
SODIUM CHROMATE	X	X	X	X				
SODIUM CYANIDE	X	X	X	X				
SODIUM DICHLOROISOCYANURATE	X	X						
SODIUM DICHROMATE (see sodium bichromate)	X	X	X	X				
SODIUM FERROCYANIDE	X	X						
SODIUM FLUORIDE	X	X	X	X				
SODIUM FORMATE	X	X		X				
SODIUM HYDRIDE, CRYSTALS		X	X	X				
SODIUM HYDROSULFIDE	X	X						
SODIUM HYDROSULFITE	X	X	X					
SODIUM HYDROXIDE, SOLID	X	X	X		X			
SODIUM HYPOCHLORITE HYDRATE			X	X				
SODIUM IODIDE	X	X		X				
SODIUM METHYLATE	X	X						
SODIUM NITRATE, SOLID		X	X	X				
SODIUM NITRITE, SOLID	X	X	X	X				
SODIUM OXALATE	X	X						
SODIUM PERBORATE		X	X					
SODIUM PERCHLORATE		X	X	X				
SODIUM PERMANGANATE		X	X					

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SODIUM PEROXIDE		x	x	x			
SODIUM PHOSPHATES	x	x					
SODIUM PICRAMATE, DRY		x	x				
SODIUM-POTASSIUM ALLOY	x	x		x			
SODIUM PYROPHOSPHATE PEROXIDE			x				
SODIUM SILICATE	x	x					
SODIUM STANNATE							
SODIUM SULFATE		x					
SODIUM SULFIDE	x	x	x	x			
SODIUM SULFITE	x	x		x			
SODIUM THIOCYANATE	x	x		x			
SODIUM THIOSULFATE	x	x					
SODIUM TRIPHOSPHATE	x	x					
SORBITOL		x					
STRONTIUM ARSENITE	x	x					
STRONTIUM CHLORATE	x	x	x				
STRONTIUM NITRATE	x	x	x				
STRONTIUM PEROXIDE		x	x				
STRYCHNINE		x		x	x		x
STYRENE (phenyl ethylene)	x	x	x	x	x	x	x
SUCCINIC ACID PEROXIDE, DRY		x	x	x			
SULFOLANE		x				x	
SULFUR		x	x	x		x	x
SULFUR CHLORIDE-mono	x	x	x				x
SULFUR DIOXIDE		x	x	x	x		x
SULFUR HEXAFLUORIDE		x	x		x		x
SULFURIC ACID	x	x	x	x	x	x	x
SULFUR TRIOXIDE		x	x	x			x

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SULFURYL CHLORIDE (sulfuric oxychloride)		x	x	x			
SULFURYL FLUORIDE		x	x	x	x		x
TANNIC ACID (TANNIN)	x	x	x	x			
TARTARIC ACID (RACEMIC ACID)		x	x				
TERTIARY BUTYL ISOPROPYL BENZENE	x	x					
TETRADECANE	x	x	x				
1-TETRADECANOL (MYRISTYL ALCOHOL)		x	x				
TETRAETHYLENE GLYCOL		x	x			x	
TETRAETHYLENE PENTAMINE	x		x	x			
TETRAETHYL LEAD (all mixes)	x	x		x		x	x
TETRAETHYL PYROPHOSPHATE	x	x		x			
TETRAFLUORETHYLENE	x	x					
TETRAHYDROFURAN		x	x	x	x		x
TETRAHYDRONAPHTHALENE (tetralin)		x	x			x	x
TETRAMETHYL LEAD	x	x		x	x		x
TETRAPROPYLENE	x	x				x	x
THALLIUM	x	x	x	x	x		x
THIOGLYCOLIC ACID	x			x			
THIONYL CHLORIDE (sulfur oxychloride)	x	x	x	x			
THIOPHENE	x	x		x			
THIOPHENOL	x	x					
THIOPHOSPHORYL CHLORIDE		x	x				
THORIUM, POWDER		x	x				x
THORIUM NITRATE	x	x	x				x
TIN TETRACHLORIDE (stannic chloride)		x	x				x
TITANIUM SULFATE	x	x					x
TITANIUM TETRACHLORIDE	x	x	x	x			x
TOLUENE (TOLUOL)	x	x	x	x	x	x	x

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TOLUENE DIISOCYANATE	X	X		X	X		
o-TOLUIDINE (2, 4-Methyl aniline)	X	X	X	X	X		X
TRIAMYLAMINE		X	X	X			
TRIBUTYLAMINE		X	X	X			
TRICHLORBENZENE		X	X	X		X	
TRICHLOROETHANE		X		X	X	X	X
TRICHLOROETHYLENE		X		X		X	X
TRICHLOROFLUOROMETHANE (FREON 11)		X	X				X
TRICHLOROFLUOROSILANE	X	X					
TRICHLOROISOCYANURIC ACID	X	X					
TRICHLOROMONOFLUOROMETHANE (see trichlorofluoromethane)			X				
TRICHLOROPHENOL	X	X					
TRICHLOROSILANE (SILICON CHLOROFORM)		X	X				
TRICRESYLPHOSPHATE			X	X			X
TRIDECANOL		X				X	X
TRIETHANOLAMINE	X	X	X			X	X
TRIETHYLAMINE	X	X	X	X	X		X
TRIETHYL BENZENE		X				X	X
TRIETHYLENE GLYCOL (dicaproate)		X	X			X	X
TRIETHYLENE TETRAMINE	X	X	X	X		X	X
TRIMETHYLAMINE	X	X	X	X			
TRIMETHYLCHLOROSILANE	X	X					
TRINITROBENZENE (TNB)	X		X	X			
TRINITROBENZOIC ACID	X	X					
TRINITRORESORCINOL (styphnic acid)		X	X			X	X
TRIPROPYLENE	X	X					
TRITIUM (HYDROGEN 3)			X				

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TURBINE OIL (see lubricating oil)			X				
TURPENTINE		X	X		X	X	X
UNDECANOL		X	X				
1-UNDECENE		X					
UNSYMETRICAL DIMETHYL HYDRAZINE	X	X					
URANYL NITRATE	X	X					
UREA (PLUS SALTS)		X					X
VALERALDEHYE		X				X	X
VANADIUM OXYTRICHLORIDE	V	Y					X
VANADIUM PENTOXIDE	X	X					
VANADIUM TETRACHLORIDE	X	X					
VANADYL SULFATE	X			X			
VARNISH			X				X
VINYL ACETATE	X	X	X	X		X	X
VINVYL BROMIDE	X		X	X			
VINYL CHLORIDE	X	X	X	X		X	X
VINYL ETHER (DIVINYL ETHER)		X	X	X			
VINYL FLUORIDE	X	X					
VINYLIDENE CHLORIDE		X	X	X		X	
VINYL METHYL ETHER, IN CYL.		X	X				
VINYL TOLUENE		X			X	X	X
VINYLTRICHLOROSILANE		X	X				
WAXES	X	Y					
XYLENE (XYLOL)	X	X	X	X	X	X	X
XYLENOLS	X	X		X			
XYLYL BROMIDE		X					
ZINC ACETATE		X					X
ZINC AMMONIUM		X					X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ZINC ARSENATE	X	X	X				X
ZINC ARSENITE	X	X	X				X
ZINC CHLORATE	X	X	X	X			X
ZINC CHLORIDE	X	X	X	X	X		X
ZINC CYANIDE	X	X	X				
ZINC ETHYL	X	X	X				
ZINC NITRATE	X	X	X				
ZINC OXIDE				X			X
ZINC PERMANGANATE	X	X	X				
ZINC PEROXIDE	X	X	X				
ZINC SULFATE	X	X					X
ZIRCONIUM, POWDER	X	X	X		X		
ZIRCONIUM PICRAMATE, DRY		X	X				

APPENDIX C-1

COMPOUNDS FOUND HAZARDOUS BY RATING SYSTEM

This appendix contains a selected list of materials whose toxic, explosive, or flammable properties may create hazardous waste conditions.

TITLE 1	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating 11	Number of Unknowns 12	Maximum Potential Effects Rating 13	Production Rating 14	Distribution Rating 15	Total Production Distribution Rating 16	Final Known Hazards Rating 17	Maximum Potential Hazards Rating 18
	Human Effects 2	Explosion Reaction 3	Ecological Effects 4	Human Effects 5	Explosion Reaction 6	Ecological Effects 7	Human Effects 8	Explosion Reaction 9	Ecological Effects 10								
Acetaldehyde	2	2	3	2	1	3	2	2	2	19		19	1 5	0	1.50	28	28
Acetic Acid	2	2	1	2	1	3	2	U	2	15	1	18	1.5	.25	1.75	26	31
Acetic Anhydride	2	2	2	3	3	2	3	2	U	19	1	22	1.5	.25	1.75	33	3
Acetone	2	2	2	2	1	1	1	2	U	13	1	16	1.5	.25	1.75	23	28
Acetone Cyanhydrin	3	2	2	3	3	3	2	2	U	20	1	23	1.5	.25	1.75	35	40
Acetonitrile (Methyl Cyanide)	2	2	2	2	2	2	1	2	U	15	1	18	1.5	.25	1.75	26	31
Acetyl Chloride	3	2	3	3	2	U	3	2	U	18	2	24	1.0	.50	1.50	27	36
Acetyiene	1	2	1	1	1	2	1	2	U	11	1	14	1.5	.25	1.75	19	24
Acridine	2	2	1	2	1	3	2	1	U	14	1	17	1.0	.25	1.25	17	21
Acrolein	3	2	2	3	U	3	2	2	U	17	2	23	1.0	.25	1.25	21	29
Acrylic Acid	3	2	2	3	1	3	3	2	U	19	1	22	1.25	.50	1.75	33	38
Acrylonitrile	2	2	3	3	1	3	1	2	U	17	1	20	1.5	.25	1.75	30	35
Aldrin	3	2	2	3	U	3	2	2	U	17	2	23	1.0	.25	1.25	21	29
Allyl Alcohol	2	2	3	2	1	3	2	2	U	17	1	20	1.0	.25	1.25	21	25
Allyl Chloride	3	2	U	3	1	1	3	1	U	14	2	20	1.0	.25	1.25	17	25
Aluminum Fluoride	3	2	2	3	U	U	2	2	3	17	2	23	1 5	.50	2.0	34	43
Aluminum Oxide (Alumina)	2	2	1	1	1	U	1	1	3	12	1	15	1 0	.25	1.25	15	19
Aluminum Sulfate	3	2	3	3	2	2	3	2	U	20	1	23	1.5	.50	2.0	40	46
Ammonia (Aqua-Ammonuim Hydroxide)	2	2	U	3	1	3	2	2	U	15	2	21	1.5	.25	1.75	26	37
Ammonium Chloride	1	2	2	1	1	2	1	1	U	11	1	14	1 25	.50	1.75	19	24
Ammonium Chromate	3	2	U	3	1	2	3	2	U	16	2	22	1 25	.50	1.75	28	38
Ammonium Dichromate	3	2	2	2	1	2	3	2	U	17	1	20	1.25	.25	1.50	25	30
Ammonium Fluoride	3	2	2	3	1	2	3	2	U	18	1	21	1.25	.50	1.75	31	37
Ammonium Nitrate	1	2	U	1	1	2	1	3	U	11	2	17	1.5	.25	2.0	22	34
Ammonium Perchlorate	2	3	U	2	1	U	2	3	U	13	3	22	1.5	.50	2.0	26	44
Ammonium Persulfate	1	2	1	1	1	3	1	2	U	12	1	15	1.25	.50	1.75	21	26
Ammonium Picrate (Dry)	3	3	1	3	1	U	3	3	U	17	2	23	1.25	.50	1.75	30	40

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Ammonium Picrate (Wet)	3	3	U	3	1	U	3	2	U	15	3	24	1.25	.25	1.5	22	36
Ammonium Sulfide	2	3	3	3	2	3	2	3	U	21	1	24	1.5	.25	1.75	37	42
Amyl Acetate (Banana Oil)	2	2	2	2	1	3	1	2	U	15	1	18	1.0	.25	1.25	19	22
Amyl Alcohol (Fusel Oil)	2	2	3	3	1	2	2	2	U	17	1	20	1.25	.25	1.5	25	30
Aniline	3	2	1	3	1	2	3	2	U	17	1	20	1.5	.25	1.75	30	35
Anthracenes	U	2	3	3	1	U	U	1	U	10	4	24	1.5	.25	1.75	18	42
Antimony	3	2	2	3	1	U	2	2	U	15	2	21	1.25	.25	1.5	22	31
Antimony Pentachloride	3	2	2	3	1	U	2	2	U	15	2	21	1.0	.25	1.25	19	26
Antimony Pentafluoride	3	2	2	3	1	U	2	2	U	15	2	21	1.0	.25	1.25	19	26
Antimony Pentasulfide	3	2	1	2	2	1	1	2	U	14	1	17	1.0	.5	1.5	17	21
Antimony Potassium Tartrate	3	2	1	3	1	3	2	2	U	17	1	20	1.0	.25	1.25	21	25
Antimony Sulfate	3	2	1	3	1	U	2	2	U	14	2	20	1.0	.25	1.25	17	25
Antimony Sulfide	3	2	1	3	2	U	2	2	U	15	2	21	1.0	.5	1.5	22	31
Antimony Triethyl (Triethylstibine)	3	3	U	3	1	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Antimony Trichloride	3	2	U	3	2	3	3	2	U	18	2	24	1.0	.5	1.5	27	36
Antimony Trifluoride	3	2	U	3	1	2	2	2	U	15	2	21	1.0	.25	1.25	19	26
Antimony Trimethyl (Trimethylstibine)	3	3	U	3	1	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Antimony Trioxide	3	2	1	3	1	3	2	2	U	17	1	20	1.0	.25	1.25	21	25
Arsenic	3	2	3	3	1	3	2	2	3	22		22	1.25	.5	1.75	38	38
Arsenic Chloride	3	2	3	3	2	3	2	2	3	23		23	1.0	.25	1.25	29	29
Arsenic Diethyl	3	3	3	3	2	3	2	3	3	25		25	1.0	.25	1.25	31	31
Arsenic Dimethyl	3	3	3	3	1	3	2	2	3	23		23	1.0	.25	1.25	29	29
Arsenic Pentaselenide	3	2	3	3	1	3	2	2	3	22		22	1.0	.25	1.25	27	27
Arsenic Trichloride	3	3	3	3	1	3	2	2	3	23		23	1.0	.25	1.25	29	29
Arsenic Trioxide	3	3	3	3	1	3	2	2	3	23		23	1.0	.25	1.25	29	29
Asbestos Particles	3	1	U	1	1	U	1	1	U	8	3	17	1.5	.25	1.75	14	30
Barium Carbonate	2	1	1	2	2	1	1	1	U	11	1	14	1.5	.25	1.75	19	24

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TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Barium Chloride	2	1	2	3	2	3	1	1	U	15	1	18	1.0	.5	1.5	22	27
Barium Cyanide	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Barium Fluoride	3	2	2	3	1	1	3	2	U	17	1	20	1.0	.25	1.25	21	25
Barium Nitrate	2	2	U	2	1	2	1	2	U	12	2	18	1.0	.25	1.25	15	22
Barium Sulfide	2	3	U	2	2	U	1	3	U	13	3	22	1.0	.25	1.25	16	27
Benzene	2	2	1	2	1	3	2	2	U	15	1	18	1.5	.5	2	30	36
Benzene Hexachloride	2	2	3	3	1	3	2	2	1	19		19	1.25	.5	1.75	33	33
Benzene Sulfonic Acid	3	2	1	3	1	2	3	2	U	17	1	20	1.0	.25	1.25	21	25
Benzoic Acid	1	1	1	1	1	2	1	1	U	9	1	12	1.25	.25	1.5	13	18
Benzyl Chloride	3	2	U	3	2	3	3	2	U	18	2	24	1.25	.25	1.5	27	36
Beryllium Carbonate	3	2	3	1	1	U	3	1	U	14	2	20	1.0	.25	1.25	17	25
Beryllium Chloride	3	2	3	2	1	U	3	2	U	16	2	22	1.0	.25	1.25	20	27
Beryllium Hydroxide	3	2	3	2	1	U	3	1	U	15	2	21	1.0	.25	1.25	19	26
Beryllium Oxide	3	2	3	1	1	U	3	1	U	14	2	20	1.0	.25	1.25	17	25
Beryllium Powder	3	2	2	3	1	3	1	2	2	19		19	1.0	.25	1.25	24	24
Beryllium Selenate	3	2	3	3	1	U	3	1	U	16	2	22	1.0	.25	1.25	20	27
Boron Trichloride	2	2	2	2	2	U	2	2	U	14	2	20	1.0	.25	1.25	17	25
Boron Trifluoride	3	1	2	2	2	U	3	1	U	14	2	20	1.0	.25	1.25	17	25
Bromic Acid	3	2	U	3	1	U	3	2	U	14	3	23	1.0	.25	1.25	17	29
Bromine	3	2	U	2	2	3	3	2	U	17	2	23	1.5	.25	1.75	30	40
Bromine Pentafluoride	3	2	U	3	2	U	3	2	U	15	3	24	1.0	.25	1.25	19	30
Butadiene	2	2	3	2	U	3	1	1	U	14	2	20	1.5	.25	1.75	24	35
Butane	2	2	1	1	1	1	1	2	U	11	1	14	1.5	.5	2.0	22	28
Butanol (Butyl Alcohol)	1	2	1	2	1	3	1	2	U	13	1	16	1.5	.5	2.0	26	32
Butene - 1 (Ethyl Ethylene)	2	2	U	1	1	U	1	2	U	9	3	18	1.5	.25	1.75	16	31
Butylacetate (Butyl Ethanoate)	1	2	1	1	1	3	1	2	U	12	1	15	1.5	.5	2.0	24	30
Butylacrylate	1	2	1	2	1	2	1	2	U	12	1	15	1.25	.25	1.5	18	22

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
n-Butylamine	2	2	1	2	1	3	2	2	U	15	1	18	1.0	.25	1.25	19	22
Butyl Mercaptan	2	2	1	2	1	U	2	2	U	12	2	18	1.0	.25	1.25	15	22
Butyl Phenol	1	2	U	1	1	U	2	2	U	9	3	18	1.0	.25	1.25	11	22
Butyraldehyde (Butyl Aldehyde - n)	1	2	1	2	1	3	1	2	U	13	1	16	1.0	.25	1.25	16	20
Cacodylic Acid (Dimethylarsinic Acid)	3	2	1	3	1	U	2	2	2	16	1	19	1.0	.25	1.25	20	24
Cadmium	3	2	3	3	1	U	1	2	U	15	2	21	1.25	.5	1.75	26	37
Cadmium Chloride	3	2	3	3	1	3	3	2	3	23		23	1.0	.25	1.25	29	29
Cadmium Cyanide	3	2	2	3	2	2	1	2	2	19		19	1.0	.25	1.25	24	24
Cadmium Fluoride	3	2	3	3	1	U	3	1	U	16	2	22	1.0	.25	1.25	20	27
Cadmium Nitrate	3	2	U	3	1	3	3	2	3	20	1	23	1.0	.25	1.25	25	29
Cadmium Oxide	3	2	2	3	1	U	1	2	U	14	2	20	1.0	.5	1.5	21	30
Cadmium Phosphate	3	2	1	3	2	U	2	2	U	15	2	21	1.0	.25	1.25	19	26
Cadmium Potassium Cyanide	3	2	U	3	2	U	3	2	U	15	3	24	1.0	.25	1.25	19	30
Cadmium Sulfate	3	2	3	3	1	1	3	1	3	20		20	1.0	.25	1.25	25	25
Calcium Arsenate	3	2	2	3	2	3	2	2	U	19	1	22	1.0	.25	1.25	24	27
Calcium Arsenide	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Calcium Carbide	1	2	U	1	2	U	1	2	U	9	3	18	1.5	.25	1.75	16	31
Calcium Cyanide	3	2	3	3	2	U	1	2	U	16	2	22	1.25	.5	1.75	28	38
Calcium Fluoride	3	2	1	3	1	U	2	2	U	14	2	20	1.5	.25	1.75	24	35
Calcium Hydride	1	2	U	1	2	U	2	2	U	10	3	19	1.0	.25	1.25	12	24
Calcium Hypochlorite	2	2	U	2	2	3	2	2	U	15	2	21	1.5	.25	1.75	26	37
Calcium Oxide	3	1	U	2	2	2	2	1	U	13	2	19	1.5	.25	1.75	23	33
Carbon Disulfide	3	2	2	3	1	3	2	2	U	18	1	21	1.5	.25	1.75	31	37
Carbon Monoxide	3	2	3	1	1	3	1	1	U	15	1	18	1.5	.25	1.75	26	31
Carbon Tetrachloride	3	2	1	3	1	2	2	2	U	16	1	19	1.5	.25	1.75	28	33
Carbonyl Chloride (Phosgene)	3	2	3	3	2	U	3	2	U	18	2	24	1.0	.25	1.25	22	30
Chloral Hydrate	2	1	1	2	1	U	1	1	U	9	2	15	1.0	.25	1.25	11	19

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Chlorine	3	2	2	2	2	3	1	2	U	17	1	20	1.25	.25	1.5	30	35
Chlorine Trifluoride	3	3	3	3	2	U	3	3	U	20	2	26	1.0	.25	1.25	25	32
Chloroacetophenone	2	2	U	1	2	U	1	2	U	10	2	16	1.0	.5	1.5	15	24
Chlorobenzene (Chlorobenzol)	2	2	1	2	1	3	1	2	U	14	1	17	1.5	.25	1.75	24	30
Chlorodene	1	1	2	1	1	3	1	1	3	14		14	1.0	.25	1.25	17	17
Chloroform (Trichloromethane)	3	2	2	1	2	3	1	2	U	16	1	19	1.5	.25	1.75	28	33
Chlorosulfonic Acid	3	2	U	3	2	3	3	2	U	18	2	24	1.5	.25	1.75	31	42
Chromic Acid	3	2	2	3	1	3	3	2	U	19	1	22	1.25	.25	1.5	28	33
Chromic Fluoride	3	2	U	3	1	U	3	1	U	13	3	22	1.0	.25	1.25	16	27
Chromic Sulfate	3	2	2	3	1	3	3	1	3	21		21	1.0	.25	1.25	26	26
Chromium Cyanide	3	2	U	3	1	U	3	1	U	13	3	22	1.0	.25	1.25	16	27
Coal (Particle)	2	2	U	1	1	U	1	2	3	12	2	18	1.5	.5	2.0	24	36
Colbalt Chloride	1	2	3	1	1	3	2	1	3	17		17	1.0	.25	1.25	21	21
Cobaltous Nitrate	1	2	2	2	1	3	1	2	2	16		16	1.0	.5	1.5	24	24
Copper Acetoarsenite	3	2	3	3	1	U	2	2	U	16	2	22	1.0	.25	1.25	20	27
Copper Cyanide (Cuprous Cyanide)	2	2	U	2	2	U	1	2	U	11	3	20	1.0	.25	1.25	14	25
Copper Nitrate	2	3	3	2	1	3	1	2	U	17	1	20	1.0	.25	1.25	21	25
Copper Sulfate	2	2	2	2	1	3	2	2	2	18		18	1.5	.5	2.0	36	36
Creosote	2	2	1	2	1	2	2	2	U	14	1	17	1.5	.25	1.75	24	30
Cresol (Cresylic Acid)	2	2	2	2	1	3	2	2	U	16	1	19	1.5	.25	1.75	28	33
Crotonaldehyde	3	2	2	3	1	3	3	2	U	19	1	22	1.0	.25	1.25	24	27
Cumene (Isopropylbenzol)	3	2	1	3	1	3	2	2	U	17	1	20	1.5	.25	1.75	30	35
Cyanides	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Cyanoacetic Acid	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Cyclohexane (Hexanhydrobenzene)	1	2	1	1	1	3	1	2	U	12	1	15	1.5	.5	2.0	24	30
Cyclohexanol (Hexalin)	1	2	1	2	1	3	1	2	U	13	1	16	1.5	.25	1.75	23	28
Cyclohexanone	1	2	1	1	1	3	1	2	U	12	1	15	1.5	.25	1.75	21	26

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Cyclohexylamine	3	2	2	2	1	U	2	2	U	14	2	20	1.25	25	1.5	21	30
Demeton	3	1	3	3	1	3	3	1	3	21		21	1.0	.25	1.25	26	26
Decyl Alcohol	1	2	U	1	1	1	1	2	U	9	2	15	1.5	.25	1.75	16	26
Dibutyl Phthalate - n	1	1	U	2	1	1	1	1	U	8	2	14	1.25	.25	1.5	14	24
o - Dichlorobenzene	2	2	1	2	1	3	2	2	U	15	1	18	1.25	.25	1.5	22	27
p - Dichlorobenzene	1	2	U	2	1	3	1	2	U	12	2	18	1.26	.25	1.5	18	27
2, 4 - Dichlorophenoxyacetic Acid (2, 4-D)	2	2	2	2	1	3	2	2	2	18		18	1.25	.25	1.5	27	27
DDD (Dichloro Diphenyl Dichloro Ethene)	1	2	2	2	1	3	1	1	U	13	1	.16	1.0	.25	1.25	16	20
DDT (Dichloro DiPhonyl-Trichloroethane)	3	1	2	2	1	3	3	1	3	19		19	1.25	.25	1.5	28	28
Diborane (Boron Hydride)	3	3	3	3	2	U	3	3	U	20	2	26	1.0	.25	1.25	25	32
Dichloroethyl Ether	3	2	U	3	2	3	1	2	U	16	2	22	1.0	.25	1.25	20	27
Dichloromethane (Methylene Chloride)	1	1	2	2	1	2	2	2	U	13	1	16	1.5	.25	1.75	23	28
1, 2 - Dichloropropane	3	2	1	3	1	3	3	2	U	18	1	21	1.25	.25	1.5	27	31
1, 3 - Dichloropropene	2	2	2	2	1	3	3	2	U	17	1	20	1.0	.25	1.25	21	25
Dieldrin	3	2	3	3	1	3	3	2	U	20	1	23	1.0	.25	1.25	25	29
Diethanolamine	1	1	1	1	1	2	1	2	U	10	1	13	1.25	.25	1.5	15	19
Diethylamine	2	2	1	3	1	2	2	2	U	15	1	18	1.0	.25	1.25	19	22
Diethyl Ether (Ethyl Ether)	2	2	1	2	1	U	1	2	U	11	2	17	1.5	.25	1.75	19	30
Diethylene Dioxide (1, 4 - Dioxane)	3	2	1	3	1	U	2	2	U	14	2	20	1.0	.25	1.25	17	25
Diethylene Triamine	2	2	1	2	1	2	2	1	U	13	1	16	1.0	.25	1.25	16	20
Diethylotilbestrol	2	1	1	2	1	U	2	1	U	10	2	16	1.0	.25	1.25	12	20
Diisobutylene	1	2	U	1	1	1	1	2	U	9	2	15	1.25	0	1.25	11	19
Diisobutyl Ketone	1	1	2	1	1	2	1	2	U	11	1	14	1.0	0	1.0	11	14
Dimethylamine	2	2	1	2	1	3	2	2	U	15	1	18	1.25	.25	1.5	22	27
Dimethyl Sulfate (Methyl Sulfate)	3	2	3	3	1	U	3	2	U	17	2	23	1.0	.25	1.25	21	29
2, 4 - Dinitroaniline	2	2	U	3	1	U	2	1	U	11	3	20	1.5	.5	2.0	22	40
Dinitro - o - Cresols	3	3	3	3	1	3	3	3	U	22	1	25	1.0	.25	1.25	27	31

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
o - Dinitrobengol (1, 2 - Dinitrobenzene)	3	3	U	3	2	3	3	2	U	19	2	25	1.0	.25	1.25	24	31
2, 4 - Dinitrophenol	3	3	3	3	1	3	2	3	U	21	1	24	1.0	.5	1.5	31	36
2, 4 - Dinitrotoluene (Dinitrotoluol)	3	3	U	3	1	3	2	2	U	17	2	23	1.5	.25	1.75	30	40
Diphenylamine (Phenylaniline)	3	2	2	3	1	U	1	1	U	13	2	20	1.25	.25	1.5	19	30
Dipropylene Glycol	1	2	1	2	1	1	1	1	U	10	1	13	1.25	.25	1.5	15	19
Dodecyl Benzene (Crude)	U	2	U	U	1	2	U	3	U	8	5	23	1.5	.25	1.75	14	40
Endrin	3	2	2	3	1	3	3	1	3	21		21	1.0	.25	1.25	26	26
Epichlorohydrin	3	2	2	3	1	3	3	2	U	19	1	22	1.5	.25	1.75	33	38
Ethane	2	2	1	1	1	U	1	1	U	9	2	15	1.5	.25	1.75	16	26
Ethanol (Ethyl Alcohol)	2	2	1	2	1	1	1	2	U	12	1	15	1.5	.25	1.75	21	26
Ethanolamine (Monoethanolamine)	2	2	1	2	1	2	2	1	U	13	1	16	1.5	.25	1.75	23	28
Ethers	1	2	1	1	1	U	1	2	U	9	2	15	1.5	.25	1.75	16	26
Ethyl Acetate (Acetic Ether)	1	2	1	2	1	1	1	2	U	11	1	14	1.5	.25	1.75	19	24
Ethyl Acrylate	3	2	1	3	1	2	3	2	U	17	1	20	1.5	.25	1.75	30	35
Ethylamine (Monoethylamine)	3	2	2	3	1	3	3	2	U	19	1	22	1.25	.25	1.5	28	33
Ethyl Benzene (Phenyl Ethane)	2	1	1	2	1	3	2	1	U	13	1	16	1.6	.25	1.75	23	28
Ethyl Chloride (Chloroethane)	2	2	U	2	2	1	1	2	U	12	2	18	1.5	.25	1.75	21	31
Ethylene (Ethene)	2	2	2	1	1	3	1	2	U	14	1	17	1.25	.25	1.5	21	25
Ethylene Bromide (Ethylene Dibromide)	3	2	2	3	1	3	3	2	U	19	1	22	1.0	.5	1.5	28	33
Ethylene Cyanohydrin	2	2	U	2	2	1	1	2	U	12	2	18	1.0	.25	1.25	15	22
Ethylene Diamine	2	2	1	2	1	3	2	1	U	14	1	17	1.25	.25	1.5	21	25
Ethylene Dibromide (Dibromethane)	2	2	3	3	1	3	2	2	U	18	1	21	1.0	.25	1.25	22	26
Ethylene Dichloride (1, 2-Dichloroethane)	3	2	1	3	1	2	2	2	U	16	1	19	1.5	.25	1.75	28	33
Ethylene Glycol (Glycol)	1	2	1	2	1	1	1	1	U	10	1	13	1.5	.25	1.75	17	23
Ethylene Glycol Monoethyl Ether	1	2	1	2	1	2	1	2	U	12	1	15	1.0	.5	1.5	18	22
Ethylene Glycol Monoethyl Ether Acetate	2	2	1	2	1	2	1	1	U	12	1	15	1.0	.25	1.25	15	19
Ethylene Oxide	2	2	1	1	1	2	2	2	U	13	1	16	1.5	.25	1.75	23	28

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Ethylenimine	3	2	3	3	1	3	3	2	U	20	1	23	1.25	.25	1.5	30	34
2-Ethylhexanol (Octyl Alcohol)	2	1	1	1	1	U	1	2	U	9	2	15	1.5	.25	1.75	16	26
Ethyl Mercaptan	2	2	U	2	2	U	2	2	U	12	3	21	1.0	.25	1.25	15	26
Ethyl Methyl Ketone (Butanone)	2	2	1	1	1	1	1	2	U	11	1	14	1.0	.5	1.5	16	21
Ethyl Phthalate (Diethyl o-Phthalate	2	1	1	2	1	3	2	1	U	13	1	16	1.0	.25	1.25	16	20
2-Ethyl - 3 Propyl Acrolein	2	2	U	2	1	2	2	1	U	12	2	18	1.0	.25	1.25	15	22
Ferrous Sulfate	1	1	2	1	1	3	1	1	U	11	1	14	1.5	.5	2.0	22	28
Fluorides (e.g., Hydrogen Fluoride, etc.	3	2	3	3	1	U	3	2	U	17	2	23	1.5	.25	1.75	30	40
Fluorine (Hydrofluoric Acid)	3	2	3	3	1	3	3	2	U	20	1	23	1.5	.25	1.75	35	40
Formaldehyde - 37% Solution	3	2	2	3	1	3	3	2	U	19	1	22	1.5	.5	2.0	38	44
Formic Acid	3	2	2	3	1	1	2	1	1	16		16	1.25	.25	1.5	24	24
Furfural (Furfuraldehyde)	2	2	2	2	1	3	2	1	U	15	1	18	1.5	.25	1.75	26	31
Furfural Alcohol	2	2	2	U	1	3	U	1	U	11	3	20	1.25	.25	1.5	16	35
Guthion	3	2	3	3	1	3	3	1	3	22		22	1.0	.25	1.25	27	27
Heptalchor	2	2	3	2	1	3	1	1	3	18		18	1.0	.25	1.25	22	22
Heptane (Heptyl Hydride)	2	2	2	1	1	2	1	1	U	12	1	15	1.5	.25	1.75	15	19
Hexachlorophene (Methylene)	1	2	3	1	1	U	3	1	U	12	2	18	1.0	.25	1.25	15	22
Hexaethyltetraphosphate	3	2	3	3	1	3	3	2	U	20	1	23	1.0	.25	1.25	25	29
Hexamethylene Diamine	2	1	U	2	1	U	2	1	U	9	3	18	1.5	.25	1.75	16	31
Hexane (Hexyl Hydride)	1	2	1	1	1	1	1	1	U	9	1	12	1.5	.25	1.75	16	21
Hydrasine (Anhydrous Diamine)	3	3	2	3	1	3	3	3	U	21	1	24	1.0	.25	1.25	26	30
Hydrobromic Acid	3	2	U	3	2	U	3	2	U	15	3	24	1.0	.25	1.25	19	30
Hydrochloric Acid (Muriatic Acid)	3	2	1	3	1	3	3	2	U	18	1	21	1.5	.5	2.0	36	42
Hydrocyanic Acid (Hydrogen Cyanide)	3	3	3	3	2	3	3	3	U	22	1	25	1.5	.5	2.0	44	50
Hydrofluoric Acid (Hydrogen Fluoride)	3	2	2	3	2	3	3	3	U	21	1	24	1.5	.25	1.75	37	42
Hydrogen Chloride Anhydrous	3	1	U	3	1	3	3	1	3	18	1	21	1.5	.25	1.75	31	37
Hydrogen Peroxide (over 52%)	3	3	2	3	1	3	3	3	U	21	1	24	1.5	.25	1.75	37	42

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p - Hydroquinone	2	1	2	2	1	3	2	1	U	14	1	17	1.25	.5	1.75	24	30
Hydrogen Sulfide	3	2	3	3	1	3	3	2	2	22		22	1.5	.25	1.75	38	38
Iodine	3	2	U	3	1	3	3	2	U	15	2	21	1.0	.5	1.5	22	31
Isobutyl Acetate	2	1	1	2	1	3	2	2	U	14	1	17	1.0	.25	1.25	17	21
Isobutyl Alcohol	2	2	1	2	2	U	3	2	U	14	2	20	1.0	.5	1.5	21	30
Isophorone	3	U	1	3	U	3	3	U	U	13	4	25	1.0	.25	1.25	16	31
Isoprene	2	1	2	2	1	3	2	2	U	15	1	18	1.5	.25	1.75	26	31
Isopropanol (Isopropyl Alcohol)	2	2	1	2	1	2	1	2	U	13	1	16	1.5	.25	1.75	23	28
Isopropyl Acetate	2	2	1	2	1	1	1	2	U	12	1	15	1.25	.25	1.5	21	26
Isopropylamine	3	1	2	3	1	3	3	2	U	18	1	21	1.25	.25	1.5	31	37
Isopropyl Ether	2	2	1	2	1	2	3	3	U	16	1	19	1.25	.25	1.5	24	28
Lead	3	2	2	3	1	U	1	2	U	14	2	20	1.5	.5	2.0	28	40
Lead Acetate	3	2	2	3	1	3	3	2	2	21		21	1.25	.25	1.5	31	31
Lead Arsenate	3	2	2	3	1	3	3	1	3	21		21	1.5	.25	1.75	37	37
Lead Arsenite	3	2	3	3	1	U	3	1	U	16	2	22	1.25	.25	1.5	24	33
Lead Carbonate	3	2	2	3	1	U	3	1	U	15	2	21	1.25	.25	1.6	22	31
Lead Chlorite	3	2	U	3	1	U	3	2	U	14	3	23	1.25	.25	1.5	21	34
Lead Cyanides	3	2	2	3	2	U	3	2	3	20	1	23	1.25	.25	1.5	30	34
Lead Nitrate	3	3	2	3	1	3	3	3	3	24		24	1.25	.25	1.5	36	36
Lead Nitrite	3	2	U	3	1	U	3	2	U	14	3	23	1.25	.25	1.5	21	34
Lead Oxide	3	2	2	3	1	U	3	2	U	16	2	22	1.25	.5	1.75	28	38
Lithium Aluminum Hydride	2	2	U	2	2	U	2	2	U	12	3	21	1.0	.25	1.25	15	26
Magnesiumo-Arsenite	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Magnesium Chlorate	2	2	1	2	1	U	2	2	U	12	2	18	1.0	.25	1.25	15	22
Magnesium Sulfate	2	1	1	1	1	1	2	1	U	10	1	13	1.5	.5	2.0	20	26
Maleic Anhydride	3	2	3	3	2	3	3	2	U	21	1	24	1.5	.5	2.0	42	48
Manganese	3	2	U	1	1	U	1	1	U	9	3	18	1.0	.25	1.25	11	22

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	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Manganese Arsenate	3	2	3	3	1	U	2	1	U	15	2	21	1.0	.25	1.25	19	26
Manganese Chloride	3	2	3	3	1	2	1	1	U	16	1	19	1.0	.25	1.25	20	29
Manganese Cyclopentadienyltricarbonyl	3	2	3	3	1	U	1	1	U	14	2	20	1.0	.25	1.25	17	25
Mercuric Chloride	3	2	3	3	1	3	3	2	U	20	1	23	1.0	.5	1.5	30	34
Mercuric Cyanide	3	2	U	3	1	3	3	2	U	17	2	23	1.0	.25	1.25	21	29
Mercuric Diammonium Chloride	3	2	U	3	1	U	3	2	U	14	3	23	1.0	.25	1.25	17	29
Mercuric Nitrate	3	3	U	3	1	3	3	3	U	19	2	25	1.0	.25	1.25	24	31
Mercuric Sulfate	3	2	U	3	1	U	3	1	U	13	3	22	1.0	.5	1.5	19	33
Mercury	3	2	U	3	1	3	3	1	U	16	2	22	1.0	.5	1.5	24	33
Mercury Compounds (Organic)	3	2	3	3	1	3	3	1	U	19	1	22	1.0	.25	1.25	24	27
Mesityl Oxide	3	2	1	3	1	3	3	1	U	17	1	20	1.0	.25	1.25	21	25
Methanol (Methyl Alcohol)	2	2	2	3	1	2	2	2	U	16	1	19	1.5	.5	2.0	32	38
Methyl Acetate	2	2	1	2	1	1	1	1	U	11	1	14	1.25	.25	1.5	16	21
Methyl Acrylate (Acrylic Esters)	3	2	3	3	1	2	3	2	U	19	1	22	1.0	.5	1.5	28	33
Methylamine (30% Solution)	3	2	2	3	1	3	3	1	U	18	1	21	1.5	.25	1.75	31	37
Methyl Amyl Alcohol	3	2	2	3	1	2	3	1	U	17	1	20	1.0	.25	1.25	21	25
Methyl Bromide (Bromomethane)	3	2	2	3	1	1	3	2	3	20		20	1.25	.25	1.5	30	30
Methyl Chloride (Chloromethane)	2	2	U	2	1	1	1	2	U	11	2	17	1.5	.25	1.75	19	30
Methyl Chloroformate	3	2	U	3	2	U	3	1	U	14	3	23	1.0	.25	1.25	17	29
Methyl Formate (Methyl Methanoate)	2	2	1	2	1	2	2	2	1	15		15	1.0	.25	1.25	19	19
Methyl Isobutyl Ketone (Hexone)	2	2	1	2	1	1	2	1	U	12	1	15	1.0	.25	1.25	15	19
Methyl Mercaptans (Methanethiol)	2	2	2	2	2	3	2	2	U	17	1	20	1.0	.25	1.25	21	25
Methyl Methacrylate Monomer	2	2	U	1	1	2	2	2	U	12	2	18	1.5	.25	1.75	21	31
Methyl Parathion	3	2	3	3	1	3	3	2	U	20	1	23	1.25	.25	1.5	30	34
Monomethylaniline (n-Methylanilins)	3	2	2	3	1	U	3	2	U	16	2	22	1.0	.25	1.25	20	27
Morpholine	2	2	2	2	1	2	2	1	U	14	1	17	1.25	.25	1.5	21	25
Naphtha (Crude)	2	1	U	3	1	2	3	1	2	15	1	18	1.0	.25	1.25	19	22

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Total Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Naphthalene (Naphthaline)	2	2	2	2	1	3	2	1	1	15	1	18	1.5	.25	1.75	26	31
Naphthylamine - beta	3	2	2	3	1	1	3	2	1	16	2	22	1.0	.25	1.25	20	27
Nickel	2	1	2	2	1	2	1	1	2	14		14	1.25	.25	1.5	24	24
Nickel Ammonium Sulfate	2	2	1	1	1	3	2	1	3	15	1	18	1.0	.25	1.25	19	22
Nickel Antimonide	3	2	1	3	2	1	3	2	1	15	3	24	1.0	.25	1.25	19	30
Nickel Arsenide	3	2	1	3	2	1	2	2	1	14	3	23	1.0	.25	1.25	17	29
Nickel Carbonyl	3	2	3	1	1	3	1	2	3	19		19	1.0	.5	1.5	28	28
Nickel Chloride	2	2	3	1	1	3	2	1	3	18		18	1.0	.5	1.5	27	27
Nickel Cyanide	3	2	1	3	2	1	2	2	3	17	2	23	1.0	.25	1.25	21	29
Nickel Nitrate	2	3	2	2	1	3	2	3	3	21		21	1.0	.25	1.25	26	26
Nickel Selenide	3	2	1	2	2	1	2	2	1	13	3	22	1.0	.25	1.25	16	27
Nickel Sulfate	2	2	3	1	1	3	2	1	[illegible]	17		17	1.25	.5	1.75	30	30
Nitric Acid	3	1	3	3	2	3	3	1	2	21		21	1.5	.25	1.75	37	37
Nitroanilene (Nitraneline - meta-para)	3	3	1	3	1	3	3	3	1	19	2	25	1.25	.5	1.75	33	44
Nitrobenzene (Nitrobenzol)	3	3	2	3	1	3	3	3	1	21	1	24	1.5	.25	1.75	37	42
Nitrochlorobenzine (meta or para)	3	2	1	3	1	1	3	1	1	13	3	22	1.5	.25	1.75	23	38
Nitroethane	2	3	1	2	1	1	2	3	1	14	2	20	1.0	.25	1.25	17	25
Nitroglycerin	3	3	3	3	1	1	2	3	1	18	2	24	1.0	.25	1.25	22	30
Nitromethane	3	2	3	3	1	1	1	2	1	15	2	21	1.0	.25	1.25	19	26
Nitroparaffins	2	2	1	2	1	1	1	1	1	9	3	18	1.0	.25	1.25	11	22
p - Nitrophenol	3	3	3	3	1	3	1	2	1	19	1	22	1.25	.25	1.5	28	33
Nitropropane (1 and 2)	2	3	2	2	1	3	1	2	1	16	1	19	1.0	.25	1.25	20	24
p - Nitrotoluol (Nitrotoluene)	2	2	1	2	1	3	2	2	1	14	1	17	1.25	.25	1.5	21	25
Nitrous Oxide	2	2	1	1	1	1	1	2	1	10	2	16	1.25	.25	1.5	15	24
Oxalic Acid	3	1	3	3	1	3	3	2	1	19	1	22	1.25	.25	1.5	28	33
Paraformaldehyde	2	2	2	3	1	1	2	1	1	13	2	32	1.0	.5	1.5	19	28
Parathion	3	2	3	3	1	3	3	2	1	20	1	23	1.25	.25	1.5	30	31

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Pentaborane	3	3	3	3	1	U	3	3	3	22	1	25	1.0	.25	1.25	27	31
Pentachlorophenol	3	2	3	3	1	3	3	1	3	22		22	1.25	.5	1.75	38	38
PETN (Pentaerythritol Tetranitrate)	2	3	U	2	1	U	2	3	U	13	3	22	1.0	.25	1.25	16	27
n - Pentane (Amyl Hydride)	1	2	1	1	1	2	1	2	U	11	1	14	1.0	.5	1.5	16	21
Perchloric Acid (≤ 72%)	3	2	U	3	1	3	3	2	U	17	2	23	1.5	.25	1.75	30	40
Perchloroethylene (Tetrachloroethylene)	2	2	U	3	1	3	2	1	U	14	2	20	1.5	.5	2.0	28	40
Perchloryl Fluoride	2	2	3	2	1	U	2	2	U	14	2	20	1.0	.25	1.25	17	25
Phenol (Carbolic Acid)	3	2	2	3	1	3	3	2	U	19	1	22	1.5	.5	2.0	38	44
Phenylhydrogine Hydrochloride	3	2	2	3	1	U	2	2	U	15	2	21	1.0	.25	1.25	19	26
Phosphoric Acid	2	2	U	2	1	3	2	1	U	13	2	22	1.5	.5	2.0	26	44
Phosphorus (Red)	1	2	U	1	1	U	1	2	U	8	2	14	1.5	.25	1.75	14	24
Phosphorus (White or Yellow)	3	3	U	3	3	3	3	3	U	21	2	27	1.5	.25	1.75	37	47
Phosphorus Oxychloride	3	2	U	3	2	U	3	2	U	15		15	1.25	0	1.25	19	19
Phosphorus Pemachloride	3	2	3	3	2	U	3	2	U	18	2	24	1.0	.25	1.25	22	30
Phosphorus Pentasulfide	3	2	U	1	2	U	2	2	U	12	3	21	1.5	.25	1.75	21	37
Phosphorus Trichloride	3	2	U	3	2	3	3	2	U	15	2	21	1.5	.25	1.75	26	37
Phthalic Acid (Terephthalic Acid)	1	1	2	1	1	3	1	1	U	11	1	14	1.5	.25	1.75	19	24
Picric Acid (Trinetrophenol)	3	3	2	3	1	3	2	3	U	20	1	23	1.0	.25	1.25	25	29
Polychlorinated Biphenyls (Askarels)	3	2	U	2	1	U	2	1	U	11	3	20	1.0	.25	1.25	14	25
Potassium Arsenite	3	2	3	3	1	3	2	2	U	19	1	22	1.5	.25	1.75	33	38
Potassium Binoxalate	1	2	U	3	1	U	3	1	U	11	3	20	1.0	.25	1.25	14	25
Potassium Chromate	3	1	3	3	1	3	3	1	3	21		21	1.5	.25	1.75	37	37
Potassium Cyanide (Solid)	3	2	3	3	2	3	2	2	U	20	1	23	1.5	.5	2.0	40	46
Potassium Dichromate	3	1	U	3	1	3	3	1	3	18	1	21	1.5	.5	2.0	36	42
Potassium Fluoride	3	2	2	3	1	1	3	2	U	15	1	18	1.5	.5	2.0	30	36
Potassium Hydroxide (Caustic Potash)	3	2	2	3	2	3	3	2	U	20	1	23	1.5	.25	1.75	35	40
Potassium Oxalate	1	2	U	3	1	U	1	1	U	9	3	18	1.0	.5	1.5	13	27

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	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Potassium Permanganate	3	2	3	3	1	3	3	2	U	20	1	23	1.5	.5	2.0	40	46
Potassium Peroxide	2	2	U	2	2	3	2	2	U	15	2	21	1.5	.25	1.75	26	37
Potassium Sulfate	1	2	2	3	1	2	2	1	U	14	1	17	1.5	.25	1.75	24	30
Potassium Sulfide	3	2	U	3	2	3	3	2	U	18	2	24	1.5	.25	1.75	31	42
Propane (L. P. Gas)	1	2	U	1	1	1	1	1	U	8	2	14	1.5	.5	2.0	16	28
Propionaldehydl (Propyl Aldehyde)	2	1	2	2	1	2	2	2	U	14	1	17	1.0	.25	1.25	17	21
Propionic Acid	2	1	2	1	1	2	1	2	U	12	1	15	1.25	.25	1.5	18	22
n - Propyl Acetate	2	2	U	2	1	2	1	1	U	11	2	17	1.25	.25	1.5	16	25
n - Propyl Alcohol	1	2	1	1	1	2	1	1	U	10	1	13	1.25	.25	1.5	15	19
Propylamine	3	2	2	3	1	3	3	1	U	18	1	21	1.25	.25	1.5	27	31
Propylene	2	1	U	1	1	1	1	2	U	9	2	15	1.5	.5	2.0	18	30
Propylene Glycol	1	2	1	1	1	1	1	1	U	9	1	12	1.5	.25	1.75	16	21
Propylene Oxide	2	2	2	2	1	1	2	2	U	14	1	17	1.5	.25	1.75	24	30
Propylene Dichloride (Dichloropropane)	3	1	1	3	1	3	3	2	U	17	1	20	1.25	.25	1.5	25	30
Pyridine	2	2	1	2	1	2	1	2	U	13	1	16	1.25	.5	1.75	23	28
Quinone	3	2	2	3	1	3	3	1	U	18	1	21	1.0	.5	1.5	27	31
Salicylic Acid	1	1	1	2	1	1	1	1	U	9	1	12	1.25	.5	1.75	16	21
Selenium Powder	3	2	3	2	1	3	2	3	U	19	1	22	1.0	.5	1.5	28	33
Silicon Tetrochloride	3	2	3	3	2	U	3	2	U	18	2	24	1.0	.5	1.5	27	36
Silver Cyanides	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.5	1.5	21	34
Sodium	3	2	U	3	2	U	2	2	U	14	3	23	1.5	.25	1.75	24	40
Sodium Amide (Sodamide)	2	2	U	3	2	U	3	2	U	14	3	23	1.5	.25	1.75	24	40
Sodium Arsenate	3	2	3	3	1	2	2	1	U	17	1	20	1.5	.5	2.0	34	40
Sodium Arsenite	3	2	3	3	1	3	2	1	3	21		21	1.5	.25	1.75	37	37
Sodium Azide	2	2	3	3	1	3	3	3	U	20	1	23	1.5	.25	1.75	35	40
Sodium Bichromate (Sodium Dicromate)	3	1	U	3	1	3	3	1	U	15	2	21	1.5	.5	2.0	30	42
Sodium Bisulfite	2	2	3	2	2	2	1	2	U	16	1	19	1.5	.5	2.0	32	38

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	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Sodium Borate	2	2	U	2	1	2	2	1	U	12	2	18	1.5	.25	1.76	21	31
Sodium Cacodylate	3	1	2	3	1	U	2	2	U	14	2	20	1.5	.25	1.75	24	35
Sodium Carbonate	2	1	1	2	1	3	2	1	1	14		14	1.5	.25	1.75	24	24
Sodium Carbonate Peroxide	2	2	U	2	1	U	2	2	U	11	3	20	1.5	.25	1.75	19	35
Sodium Chlorate	2	1	1	2	1	1	2	1	3	14		14	1.5	.5	2.0	28	28
Sodium Chromate	3	1	3	3	1	2	3	1	U	17	1	20	1.5	.25	1.75	30	35
Sodium Cyanide	3	2	3	3	2	3	2	2	U	20	1	23	1.5	.25	1.75	35	40
Sodium Fluoride	3	2	3	3	1	3	3	1	2	21		21	1.25	.5	1.75	37	37
Sodium Formate	3	1	U	3	1	2	3	1	U	14	2	20	1.5	.5	2.0	28	40
Sodium Hydride (Crystals)	3	2	U	3	2	U	2	2	U	14	3	23	1.5	.25	1.75	24	40
Sodium Hydrosulfite	2	2	U	2	2	3	1	2	U	14	2	20	1.25	.25	1.5	21	30
Sodium Hydroxide (Caustic Soda)	2	2	1	2	2	3	3	2	U	17	1	20	1.5	.5	2.0	34	40
Sodium Iodide	2	2	2	2	1	3	1	1	U	14	1	17	1.5	0	1.5	21	25
Sodium Nitrate (Solid)	2	2	3	2	1	1	1	2	U	14	1	17	1.5	.25	1.75	24	30
Sodium Nitrite (Solid)	3	U	2	3	U	3	1	U	U	12	4	24	1.5	.5	2.0	24	48
Sodium Oxalate	1	2	3	3	1	1	3	1	U	15	1	18	1.5	.5	2.0	30	36
Sodium Oxide	2	1	2	3	2	3	3	2	U	18	1	21	1.5	.25	1.75	31	37
Sodium Perchlorate	2	2	2	2	1	3	2	2	U	16	1	19	1.5	.25	1.75	28	33
Sodium Peroxide	3	2	U	3	2	3	2	2	U	17	2	23	1.5	.25	1.75	30	40
Sodium Phosphate	U	2	2	3	1	U	2	1	U	11	3	20	1.5	.5	2.0	22	40
Sodium-Potassium Alloy	2	2	U	2	1	U	2	2	U	11	3	20	1.5	.25	1.75	19	35
Sodium Sulfide	1	2	3	3	2	3	2	3	U	19	1	22	1.5	.5	2.0	38	44
Sodium Sulfite	2	2	2	2	2	2	1	2	U	15	1	18	1.5	.5	2.0	30	36
Sodium Thiocyanate (Sodium Sulfocyanide)	1	2	2	3	1	U	1	1	U	11	2	17	1.5	.25	1.75	19	30
Stannic Chloride	3	1	U	3	2	U	3	2	U	14	3	23	1.0	.25	1.25	17	29
Stannous Chloride	2	2	3	2	1	U	2	1	U	13	2	19	1.0	.25	1.25	16	24
Strontium	2	2	U	2	2	U	2	2	U	12	3	21	1.25	.25	1.5	18	31

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Styrene (Phenyl Ethylene)	2	2	1	2	1	3	2	1	U	14	1	17	1.5	.5	2.0	28	34
Sulfur Dioxide	3	2	2	3	2	3	3	2	3	23		23	1.5	.25	1.75	40	40
Sulfur Trioxide	3	2	U	3	2	U	3	2	U	15	3	24	1.0	.25	1.25	19	30
Sulfuric Acid	3	2	2	3	2	3	3	2	U	20	1	23	1.5	.5	2.0	40	46
Sulfurous Acid	3	2	U	3	1	U	3	1	U	13	3	22	1.0	.25	1.25	16	27
Sulfuryl Fluoride	3	2	3	1	2	U	2	2	U	15	2	21	1.0	.25	1.25	19	29
Tantalum	2	2	U	1	1	U	2	1	U	9	3	18	1.0	.5	1.5	13	22
Tar (Liquid)	3	2	U	3	1	U	3	1	U	13	3	22	1.5	.5	2.0	26	44
Tear Gas (CN)	3	2	U	1	1	U	3	2	U	12	3	21	1.0	.25	1.25	15	26
Tetrachloroethane (Acetylene Tetrachloride)	3	2	3	3	1	U	2	2	U	16	2	22	1.0	.25	1.25	20	27
Tetraethyl Lead	3	2	3	3	1	3	3	2	3	23		23	1.5	.25	1.75	40	40
Tetrahydrofuran	3	2	U	3	1	U	3	2	U	14	3	23	1.0	.5	1.5	21	29
Tetramethyl Lead	3	2	2	3	1	U	3	2	3	19	1	22	1.25	.25	1.5	28	33
Tetranitromethane	3	3	3	3	1	U	3	3	U	19	2	24	1.0	.25	1.25	24	30
Thallium	3	2	3	3	1	U	1	1	U	14	2	20	1.0	.5	1.5	21	30
Thallium Sulfate	3	2	3	3	1	U	1	1	2	16	1	19	1.0	.5	1.5	24	28
Titanium Tetrachloride	3	2	U	1	2	3	3	2	3	19	1	22	1.0	.25	1.25	24	27
Toluene (Tolyol)	2	2	1	2	1	3	2	2	U	15	1	18	1.5	.5	2.0	30	36
Toluene Disocyanate	3	2	1	3	1	U	3	1	U	14	2	20	1.0	.25	1.25	17	25
Toluidine - o (2, 4-methylanilene)	3	2	2	3	1	2	2	1	U	16	1	19	1.0	.25	1.25	20	24
Trichlorobenzene	2	1	U	2	1	3	1	1	1	12	1	15	1.25	.25	1.5	18	22
Trichloroethane (α or β)	2	2	2	2	1	3	1	2	U	15	1	18	1.5	.25	1.75	26	31
Trichloroethylene	3	2	1	2	1	2	2	2	U	15	1	18	1.5	.25	1.75	26	31
Trichlorofluoromethane (Freon 11)	1	2	U	1	1	2	1	2	U	10	1	13	1.5	.25	1.75	17	23
Triethanolamine	1	2	1	1	1	3	1	1	U	11	1	14	1.25	.25	1.5	16	21
Triethylamine	3	2	2	3	1	3	3	2	U	19	1	22	1.0	.5	1.5	28	33
Triethylene Glycol	1	2	2	2	1	1	1	1	U	11	1	14	1.25	.5	1.75	19	24

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Triethylene Tetramine	3	1	U	3	1	3	3	1	U	15	2	21	1.0	.25	1.25	19	26
Trimethylamine	2	2	U	1	1	2	1	1	U	10	2	16	1.25	.25	1.5	15	24
Tri-o-Cresyl Phosphate	2	2	U	3	1	U	2	1	U	11	3	20	1.25	.25	1.5	16	30
Turpentine	1	2	U	2	1	3	1	1	U	11	2	17	1.5	.5	2.0	22	34
Vanadium Pentoxide	3	2	3	1	1	U	1	1	3	15	1	18	1.0	.25	1.25	19	22
Vanadium Sulfide	2	2	3	1	1	U	1	1	U	11	2	17	1.0	.25	1.25	14	21
Vinyl Acetate	1	2	3	1	1	3	1	1	U	13	1	16	1.5	.25	1.75	23	28
Vinyl Chloride	2	2	U	2	1	1	2	2	U	12	2	18	1.5	.25	1.75	21	31
m - Xylene (Xylox)	1	2	1	1	1	3	1	1	1	12		12	1.5	.25	1.75	21	21
Xylenol (3, 5-Dimethylphenol)	3	1	2	3	1	3	3	1	U	17	1	20	1.25	.25	1.5	25	30
Zinc Arsenate	3	2	U	3	1	U	2	1	U	12	3	21	1.0	.25	1.25	15	26
Zinc Arsenite	3	2	U	3	1	U	2	1	U	12	3	21	1.0	.25	1.25	15	26
Zinc Chloride	2	2	3	1	1	3	2	2	U	16	1	19	1.25	.5	1.75	28	33
Zinc Cyanide	3	2	U	3	2	U	2	2	U	14	3	23	1.0	.25	1.25	17	29
Zinc Nitrate	2	3	U	2	1	3	1	3	U	15	2	21	1.0	.5	1.5	22	26
Zinc Oxide	2	1	3	1	1	3	1	1	U	13	1	16	1.5	.5	2.0	26	32
Zinc Permanganate	3	2	U	3	1	U	1	1	U	11	3	20	1.0	.25	1.25	14	25
Zinc Peroxide	2	2	U	1	2	3	1	2	U	13	2	19	1.0	.25	1.25	16	24
Zinc Sulfide	2	2	U	1	2	U	1	2	U	10	3	18	1.0	.25	1.25	12	24

APPENDIX C-2

COMPOUNDS FOUND MARGINALLY HAZARDOUS BY RATING SYSTEM

The following compounds were initially considered for inclusion to the list of Appendix C-1. The ratings received indicated that they were of lesser probable hazard potential than other compounds. They have been included in this appendix to illustrate that various cutoff points may be established to differentiate between potentially hazardous compounds.

TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Final Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Adipic Acid	U	1	1	U	1	2	U	1	U	6	4	18	1.5	.25	1.75	10	31
Aminoethylethanolamine	1	1	U	U	1	1	2	1	U	7	3	16	1.0	.25	1.25	9	20
Bismuth	1	2	U	1	1	U	1	2	U	8	3	17	1.0	.25	1.25	10	21
Boric Acid	2	U	1	2	U	1	1	U	U	7	4	19	1.5	.5	2.0	14	38
Calcium Chloride	1	2	1	1	1	2	1	2	U	11	1	14	1.5	.25	1.75	19	24
Calcium Phosphate	U	2	U	U	1	U	U	2	U	5	6	23	1.5	.5	2.0	10	46
Camphor	1	2	1	2	1	1	1	2	U	11	1	14	1.0	.25	1.25	14	17
Citric Acid	1	1	1	1	1	2	1	1	U	9	1	12	1.5	.25	1.75	16	21
Copper (Dust)	2	2	U	2	1	U	1	1	U	9	3	18	1.5	.25	1.75	16	31
Dichlorodifluoromethane (Freon 12)	1	2	U	1	1	1	1	2	U	9	2	15	1.5	.25	1.75	16	26
Dichlorotetrafluoroethane (Freon 114)	1	2	U	1	1	U	1	2	U	8	3	17	1.25	.25	1.5	12	25
Dicyclopentadiene	U	2	1	U	1	U	U	2	U	6	5	21	1.25	.25	1.5	9	31
Diethylene Glycol	1	1	1	1	1	1	1	1	U	8	1	11	1.5	.25	1.75	14	19
Disopropanolamine	U	1	U	U	1	U	U	1	U	3	6	21	1.0	.25	1.25	4	26
Ethylphenol	U	1	U	U	1	U	U	2	U	4	6	22	1.0	.25	1.25	5	27
Glycerine (Glycerol)	1	1	1	1	1	1	1	1	U	8	1	11	1.5	.25	1.75	14	19
1 - Heptene (α - Heptylene)	2	U	U	1	U	1	1	U	U	5	5	20	1.5	.25	1.75	9	35
Isobutylene	U	2	U	U	1	U	U	2	U	5	6	23	1.5	.25	1.75	9	40
Isopentane	1	2	U	U	1	U	U	2	U	6	5	21	1.5	.25	1.75	10	37
Manganese Sulfate (Manganous Sulfate)	1	U	2	1	U	2	1	U	U	7	4	19	1.25	.5	1.75	12	33
Nonylphenol	U	1	U	U	1	3	U	1	U	6	5	21	1.25	.25	1.5	9	31
Oleic Acid	U	1	U	1	1	U	1	1	U	5	4	17	1.0	.25	1.25	6	21
Phthalic Anhydride	1	1	U	1	1	U	1	1	U	6	3	15	1.5	.25	1.75	10	26
Polypropylene Glycol Methyl Ether	U	U	U	U	U	U	U	U	U	0	9	27	1.5	.5	1.25		
Polyvinylchloride	U	2	U	U	1	U	U	1	U	4	6	22	1.5	.5	2.0	8	44
Potassium Phosphate	U	U	U	U	U	2	U	U	U	2	8	26	1.5	.5	2.0	4	52
Pyrenes	U	2	U	3	1	U	U	1	U	7	5	22	1.5	.25	1.75	12	38

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TITLE	AIR DISPOSAL			WATER DISPOSAL			LAND DISPOSAL			Total Known Effects Rating	Number of Unknowns	Maximum Potential Effects Rating	Production Rating	Distribution Rating	Total Production Distribution Rating	Total Known Hazards Rating	Maximum Potential Hazards Rating
	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects	Human Effects	Explosion Reaction	Ecological Effects								
Oxygen	1	2	1	1	1	1	2	2	1	12		12	1.5	.5	2.0	24	24
Silica	3	1	U	1	1	U	1	1	U	8	3	17	1.0	.25	1.25	10	21
Sodium Silicate	1	1	U	1	1	1	1	1	U	7	2	13	1.5	.25	1.75	12	23
Sorbitol	U	1	U	U	1	U	U	1	U	3	6	21	1.5	.25	1.75	5	37
Sulfur	1	1	1	1	1	1	1	1	U	8	1	11	1.5	.5	2.0	16	22
Tetrapropylene	1	1	U	1	1	1	1	1	U	7	2	13	1.5	.25	1.75	12	23
Thiocyanates	1	2	U	1	1	U	2	1	U	8	3	17	1.0	.25	1.25	10	21
Tripropylene (Nonene)	1	1	1	1	1	1	1	1	U	8	1	11	1.5	.25	1.75	14	19
Urea	1	1	U	1	1	1	1	1	U	7	2	13	1.5	.5	2.0	14	26
Zinc Chlorete	1	2	U	1	1	U	1	2	U	8	3	17	1.0	.25	1.25	10	21
Zinc Ethyl (Zinc Diethyl)	1	3	U	1	1	U	1	3	U	10	3	19	1.0	.25	1.25	12	24

APPENDIX D-1

ACCIDENTS INVOLVING HAZARDOUS SUBSTANCES

A logical approach to the development of an indepth hazardous-substance accident analysis is to obtain and analyze extensive amounts of statistical data relating to:

- Reporting of accidents (e.g., frequency, apparent causes, human factors, effects, etc.)
- Materials involved in accidents (e.g., weights or volumes of hazardous materials, hazardous material properties, container characteristics, etc.)
- Disposal problems (e.g., effects of quantity, characteristics of the environment such as meteorological conditions and terrain features including soil, vegetation, and drainage pattern, details of handling problems such as salvage possibilities and specific handling instructions, etc.).

It was quickly apparent during this study that data do not exist in the detail required to determine both direct and indirect accident causes, to assess fault where human error may be frequently involved, and to promulgate preventive measures that would be applicable to a wide spectrum of environmental conditions. Further search of the literature revealed that other researchers have approached similar problems concerning hazardous materials accidents and have reached the same conclusion with respect to availability of suitable data. For example, a very recent study by Booz, Allen and Hamilton, Inc. (Reference 1) examined the problems of hazardous materials handling, transportation, and disposal. The study and report developed the nature and magnitude of problems associated with hazardous materials and examined, quantitatively, the accident experience of the past. The study concluded that extensive data gaps exist in hazardous materials statistics which preclude the development and use of a sophisticated accident analysis and forecasting technique. Data deficiencies were assessed in the following areas:

- Accident reporting
- Accident frequency
- Accident causes
- Accident effects
- Materials involved in accidents
- Handling quantities

- Disposal quantities
- Effects of disposal.

The Booz, Allen and Hamilton study and report developed an initial overview of the hazardous materials situation despite the severe data limitations. Following is a brief summary of the approach and findings of the study. Additional information in the form of tables and matrices, has been extracted directly from the Booz, Allen and Hamilton report,and are included as tables at the end of this appendix.

From many available classification schemes for the systematic categorization of toxic or hazardous materials, a set of categories was selected which related closely to the categories and definitions contained in the Code of Federal Regulations Titles 46 and 49 (See Table D-1-1 for categories and definitions).

Trends in the production and transportation of hazardous materials were developed as were estimates of quantities of hazardous substances to be handled and transported during the period of the 1970's. (See Table D-1-2 for Hazardous Material Production Trends 1957-59 to 1968 and Projections to 1980).

A number of cogent observations were presented concerning production, transportation, and accidents involving hazardous materials. Details concerning these observations are given in the report. Several observations most pertinent to the present study are summarized below:

- Total hazardous material quantities transported are projected to increase by almost 55 percent during the next ten years (growth rate of hazardous materials production is estimated at one and one-half times the Gross National Product growth rate).
- Hazardous materials will comprise an increasing proportion of total intercity freight traffic.
- The proportion of the total volume of hazardous materials transported by pipeline is expected to increase relative to other transport modes.
- Historically, accident frequency rates (accidents per unit of traffic) for hazardous materials have increased for railroad and water carriers and declined for motor carriers.

- Projections to 1980 of both total accident occurrences and occurrence of accidents involving hazardous substances show increases.

- There is a distinct possibility of increased severity of disaster due to trends toward large unit packages of hazardous materials and large groupings of these packages.

- The approach to reduction of disaster from the presence of hazardous materials in general cargo appears to lie in action to reduce transportation accidents in general. Also specific precautionary action could be taken for shipments composed all, or mostly all, of hazardous materials.

The total environment surrounding operations involving hazardous substances includes both the natural environment and that created by specific handling procedures and transportation operations. The Booz, Allen and Hamilton report discusses a number of stresses that evolve in the total environment. The natural environmental stresses include ambient temperature, amount and rates of precipitation, changes in air pressure, and severe or unusual weather conditions. Each of these stresses or conditions may have impact on all matter, personnel, equipment, and hazardous materials in process of handling, movement, or storage.

Handling and transportation operations include all of the mechanical stresses inherent in the major modes of transportation which involve handling, loading and unloading, transporting, marshalling, and long-term storage. Such stresses include shock and vibration, impact, compression, puncture and pressure, and abrasion.

The Booz, Allen and Hamilton report developed a number of observations concerning the stresses that are operative in the total transportation environment and which may contribute to accidents involving hazardous materials. Detailed discussions of these observations are presented in the report. Following are summarized a number of observations of importance to the present study:

- Any or all of the natural environmental stresses may contribute directly or indirectly to the cause of accidents involving hazardous materials.
- Shock and vibration are the dominant factors inherent in all parts of the loading-transport-unloading cycle.
- The severity of the working environment is greatest in those areas where personnel discretion is greatest; e.g., in handling by hand, forklift, crane, hose, etc. Handling shock is primarily a result of careless personnel practices and is therefore difficult to predict.

- Transit stresses are more predictable and are primarily a function of the transportation equipment and the right-of-way.

- Condition of the right-of-way is perhaps the most basic factor bearing on the accident environment. More important statistically is maintenance of the vehicle and its safety equipment.

- Marshalling activities, between loading/unloading and transport, may cause some of the most severe shocks involved in the transportation cycle (e.g., impacts with loading docks, railroad car switching, ship docking, aircraft landings, etc.).

- Inadequate maintenance of rolling equipment is a significant contributing factor in accidents. Correction is complicated by the fact that much is owned, controlled, and/or loaded/unloaded by the owner of the commodity rather than the operator of the transport system.

- Certain failure modes of currently used containers can and do,seriously aggravate the scope of the hazard when an accident occurs.

- A survey of 230 spills of hazardous materials to the environment from a variety of storage, transportation, and industrial media indicates no specific pattern or causative factors. (A detailed summary of representative accidents involving handling and transportation of hazardous materials as prepared for the Booz, Allen and Hamilton report, is included in Table D-1-3.

Table D-1-1

Categories and Definitions of Toxic or Hazardous Materials

Classification/Category	General Nature of Hazard
Flammable Materials	Fire with attendant property damage, personal injury, or loss of life. Includes both liquids and compressed flammable gases.
Compressed Gases	Nonflammable explosion; possible property damage, personal injury, or loss of life.
Corrosive Materials	Severe damage to living tissue, acids, for example, causing personal burns and possible loss of life; property damage mostly to plant life.
Explosives	Contact hazards of fire or explosion; property damage; personal injury or loss of life.
Oxidizing Agents	Fire and explosion, depending on material they come in contact with. Property damage, personal injury, or loss of life.
Poisons	Personal sickness and possible death from both direct and indirect effect (pesticides); same for animals. Can be of long-range in effected area.
Etiologic Materials	Infectious disease-producing materials. Personal sickness and death. Also possible long range in effected area.
Cryogenic Materials	Extremely low temperature. Dangerous to living tissue; personal injury.
Radioactive Materials	Radioactive emissions both short- and long-term. Personal sickness and death.
Molton Materials	High temperature and heat content; fire producing. Property damage and personal injury.

Table D-1-2
Hazardous Material Production Trends, 1957-59 to 1968 and Projections to 1980

	Annual Production		Projected Annual Production			Percent Increase		Annual Growth Rate	
	1957-59 Average	1968	1970	1975	1980	1957-59/1968	1968/1980	1957-59/1968	1968/1980
FLAMMABLE MATERIALS									
. Total Refined Petroleum Products (Mils. of Bbls.)	3,013	4,044	4,324	5,110	6,040	34.2%	49.4%	3.0%	3.4%
Gasoline (Mils. of Bbls.)	1,433	1,940	2,080	2,420	2,820	35.4	44.2	3.1	3.1
. Paints and Varnishes (1957-59 = 100)	100	130	138	160	185	10.0	42.3	2.6	3.0
. Plastics Materials (1957-59 = 100)	100	399	505	911	1,641	299.0	311.3	14.8	12.5
. Crude Petroleum (Mils. of Bbls.)	2,547	3,329	3,560	4,070	4,600	30.7		2.7	
COMPRESSED GASES									
. LP Gas (Mils. of Gallons)	7,104	14,500	16,725	23,900	24,150	104.1	135.5	7.4	7.4
. Industrial Gases (1957-59 = 100)	100	249	329	662	1,331	149.0	434.5	9.5	15.0
. Anhydrous Ammonia (Mils. of Sht. Tons)	4,044	12,093	16,000	32,175	64,700	199.0	166.1	11.6	15.0
. Dry Natural Gas (Bils. of Cu. Ft.)	11,252	19,255	21,391	27,824	36,193	71.1	88.0	5.5	5.4
. Chlorine (Mils. of Sht. Tons)	6	12	14	22	31				
CORROSIVE MATERIALS									
. Total Corrosive Materials (Mils. of Sht. Tons)	24,816	45,052	51,099	70,010	95,919	81.5	112.9	6.1	6.5
Sulfuric Acid (Thous. of Sht. Tons)	16,673	28,383	31,591	41,288	53,962	70.2	90.1	5.5	5.5
EXPLOSIVE MATERIALS									
. Industrial High Explosive Shipments (Mils. of Lbs.)	874	1,582	1,777	2,378	3,183	81.0	101.2	6.1	6.0
. Ammunition and Other (Mils. of Lbs.)	1,000	2,400	2,600	3,200	4,800				
OXIDIZING AGENTS									
. Ammonium Nitrates (Thous. of Sht. Tons)	2,673	5,223	6,036	8,665	12,440	95.4	138.2	6.9	7.5
. Chlorates and Bleaches	270	700	860	1,440	2,320				
POISONS									
. Agricultural Pesticides (Mils. of Lbs.)	545	1,013(1)	1,409	2,129	3,215	85.9(1)	217.4(1)	8.1(1)	8.6(1)
. Inorganic Poisons and other Pesticides (Mils. of Lbs.)	1,000	1,200	1,380	1,540	1,760	20.0	46.7	1.8	3.2
RADIOACTIVE MATERIALS (Thous. of Sht. Tons)	—	17	28	50	163		858.8		20.7
ETIOLOGICAL AGENTS (Mils. of Sht. Tons)		8	—	—	—				
MOLTEN MATERIALS (Mils. of Sht. Tons)	4	13	15	26	41	225.0	215.4	12.5	10.0
CRYOGENIC MATERIALS									
. Liquified Natural Gas (Mils of Gals.)	5,642	8,390	9,300	12,500	16,000	48.7	90.7	4.0	5.5
. Liquefied Industrial Gases (Mils. of Tons)	3	8	9	18	36	166.7	350.0	10.3	13.6

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(1) Based on 1966 Estimates.

Source: Exhibits B 2 through B-9 and supporting data.

Table D-1-3
Composite and Representative Hazardous Materials Accident Summary

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
APRIL 16, 1947				X			LARGE		X					552	>3000	X			X			550,000			UNLOADING
MAY 13, 1949	X						24			X				–	40	X			X			1,000			EN ROUTE
MAY 19, 1950				X			420		X					31	>350	X			X			>10,000			LOADING
JULY 7, 1951	X							2,000,000					X	–	3	X			X			> 1,000			CHAIN REACTION AT STORAGE FACILITY
DECEMBER 3, 1956				X			18½		X					10	247	X				X		10,000			LOADING/UNLOADING
OCTOBER 7, 1959				X			6½			X				13	>125	X			X			9,000			PARKED ON CITY STREET
AUGUST 1, 1961					X				X					–	–			X				–			13,000 PEOPLE EVALUATED
JULY 30, 1964			X				LARGE		X					–	–	X			X			–			LOADING
JANUARY 12, 1966				X						X				1	2	X			X			100	PERIOD OF MOTOR CARRIER ACCIDENT SUMMARY		–
JANUARY 18	X									X				1	1	X					X	33			EN ROUTE
JANUARY 31	X									X				2	–	X				X		35			LOADING
MAY 20	X									X				3	–	X			X			27			EN ROUTE
JUNE 30		X								X				1	–	X				X		22			EN ROUTE
JULY 8		X								X				1	–	X			X			750			UNLOADING
JULY 21	X									X				1	1	X				X		8			EN ROUTE
AUGUST 29	X									X				–	1	X			X			10			EN ROUTE
SEPTEMBER 1	X									X				1	–	X				X		12			EN ROUTE
SEPTEMBER 13	X									X				1	–	X			X			EXTENSIVE			LOADING
SEPTEMBER 16	X									X				1	–	X				X		11			EN ROUTE
NOVEMBER 21	X									X				–	1	X					X	50			EN ROUTE
DECEMBER 19	X									X				5	3	X					X	38			EN ROUTE
DECEMBER 22	X									X				2	–	X					X	20			EN ROUTE
FEBRUARY 27, 1967	X									X				–	2	X				X		12			EN ROUTE
MARCH 13	X									X				–	1	X			X			–			UNLOADING
MAY 3				X						X				–	2	X				X		350			EN ROUTE
AUGUST 10	X									X				1	–	X				X		27			EN ROUTE
AUGUST 12	X									X				5	24	X				X		75			EN ROUTE
AUGUST 29	X									X				1	–	X				X		60			EN ROUTE
SEPTEMBER 5	X									X				1	2	X			X			61			EN ROUTE
OCTOBER 3					X			85		X				–	8			X			X	35			EN ROUTE
OCTOBER 6					X					X				–	1	X					X	8			EN ROUTE
OCTOBER 17	X									X				1	1	X				X		38			LOADING
OCTOBER 21			X							X				–	–	X			X			5			UNLOADING
NOVEMBER 20				X						X				–	3	X				X		42			–

Table D-1-3
(Continued)

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
1967				X						X				–	–							–	PERIOD OF MOTOR CARRIER ACCIDENT SUMMARY		8 ACCIDENTS WITH NO ADDITIONAL INFORMATION
1967	X									X				–	–							–			7 ACCIDENTS WITH NO ADDITIONAL INFORMATION
JANUARY 1, 1968	X				X		LARGE	20,000			X			–	–		X			X		EXTENSIVE			FIRE LASTED 2 DAYS—FISH KILL EXTENDED 65 MILES
JANUARY 11	X									X				–	–	X				X		25			PARKED
FEBRUARY 12	X									X				–	1	X				X		12			EN ROUTE
FEBRUARY 24						X				X				–	14			X			X	30			PARKED-MINOR CONTAMINATION OF PERSONNEL
MARCH 12		X								X				–	1							35			UNLOADING
JULY 15	X													–	–	X					X	25		PERIOD OF HAZARDOUS MATERIAL SPILL SUMMARY	UNLOADING
AUGUST 12			X				400		X					–	–	X						–			–
SEPTEMBER 3	X									X				–	1	X					X	24			EN ROUTE
OCTOBER 8	X							300					X	–	–	X					X	–			FIRE DID NOT OCCUR
OCTOBER 29		X								X				–	–	X					X	200			EN ROUTE
NOVEMBER 1	X									X				2	1	X					X	31			EN ROUTE
NOVEMBER 17				X			21			X				–	2			SMALL	X			–			EN ROUTE
NOVEMBER 18				X			20			X				1	1			SMALL		X		SMALL			EN ROUTE
DECEMBER 6	X									X				1	–	X					X	29			EN ROUTE
DECEMBER 11	X									X				–	2	X					X	200			EN ROUTE
DECEMBER 16					X						X			–	–		X				X	–			–
DECEMBER 24	X									X				1	1	X					X	20			EN ROUTE
DECEMBER 30	X									X				2	–	X					X	2000			EN ROUTE
1968				X						X				–	–							–			3 ACCIDENTS INVOLVING FIRE
1968	X									X				–	–							–			79 ACCIDENTS INVOLVING FIRE
1968					X		SMALL			X				–	8			SMALL				–			3 ACCIDENTS INVOLVING SPILLAGE EN ROUTE

Table D-1-3
(Continued)

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
JANUARY 2, 1969	X							90,000					X	–	–	X						MINOR	PERIOD OF MOTOR CARRIER ACCIDENT SUMMARY PERIOD OF TANK CAR DERAILMENT SUMMARY	PERIOD OF OIL SPILL SUMMARY PERIOD OF HAZARDOUS MATERIAL SPILL SUMMARY	–
JANUARY 3	X									X				–	12	X				X		200			LOADING
JANUARY 5		X						40,000			X					X				X		–			EN ROUTE
JANUARY 7	X							100,000					X			X						–			–
JANUARY 12			X					20,000			X					X					X	–			EN ROUTE
		X						60,000								X				X		–			
JANUARY 14	X							700,000				X				X						–			RESIDENTS EVACUATED
JANUARY 15		X						80,000			X					X				X		–			EN ROUTE
JANUARY 17	X									X				2	–	X					X	30			EN ROUTE
JANUARY 25		X						280,000			X			2	33	X				X		3,500			EN ROUTE
JANUARY 27		X								X				–	2	X				X		30			EN ROUTE
JANUARY 30	X							100,000	X					–	–	X				X		–			SINKING
FEBRUARY 2	X									X				–	1	X					X	60			LOADING
FEBRUARY 7		X								X				–	–	X				X		30			EN ROUTE
FEBRUARY 13	X							1,200	X							–						–			–
FEBRUARY 18	X							60,000			X			–	–	X						–			EN ROUTE
					X			20,000								X									
FEBRUARY 20	X							100 000	X					–	–	X					X	–			COLLISION
FEBRUARY 23	X							3,000				X		–	–	X					X	–			–
FEBRUARY 25	X							4,000	X					–	–	X					X	–			COLLISION
MARCH 3	X							80,000				X		–	–	X					X	–			–
MARCH 3	X							80,000			X			–	–	X				X		–			EN ROUTE
MARCH 4	X							40,000	X					–	–	X					X	–			EN ROUTE
MARCH 4		X						100,000			X			–	–	X				X		–			EN ROUTE
MARCH 7	X									X				–	1	X				X		100			EN ROUTE
MARCH 14	X							20,000					X	–	–	X					X	–			VANDALISM
					X			500																	
MARCH 18		X						20,000			X			–	–	X					X	–			EN ROUTE – NO FIRE
MARCH 20	X							1,000		X				–	–	X					X	–			EN ROUTE
MARCH 27	X									X				1	66	X				X		1,000			UNLOADING
APRIL 1	X									X				–	1	X				X		1,000			EN ROUTE
APRIL 2	X									X				–	1	X				X		60			LOADING/UNLOADING
APRIL 6	X								X					–	–		X				X	SOME			BUSINESS AREA EVACUATED – FIRE EXTENDED TO BRIDGE
APRIL 7	X							4,000		X				–	–	X					X	–			EN ROUTE – NO FIRE
APRIL 7	X							24,000	X					–	–	X						–			–

Table D-1-3
(Continued)

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
APRIL 10, 1969	X							4000	X					–	–	X						–	PERIOD OF MOTOR CARRIER ACCIDENT SUMMARY PERIOD OF TANK CAR DERAILMENT SUMMARY	PERIOD OF OIL SPILL SUMMARY PERIOD OF HAZARDOUS MATERIAL SPILL SUMMARY	–
APRIL 13				X						X				1	4	X				X		125			EN ROUTE
APRIL 15		X						20,000			X			–	–	X					X	–			–
APRIL 16	X							40,000			X			–	–	X						–			COMMODITY BURNED – TANKS INTACT
APRIL 17					X			150	X					–	–							–			CONTAINERS ACCOUNTED FOR
APRIL 21	X							10,000			X			–	–		X			X		–			EN ROUTE
APRIL 22	X							96,000					X	–	–	X						–			–
APRIL 25	X							40,000			X			–	–			X			X	–			EN ROUTE
APRIL 25	X							20,000			X			–	–			X			X	–			EN ROUTE – NO FIRE
APRIL 27			X					–	X					–	–						X	–			SALVAGED FROM SUNKEN BARGE
APRIL 29			X					20,000			X			–	–	X				X		–			DELAYED RUPTURE
APRIL 30	X							2000	X					–	–	X						–			–
MAY 1, 1969		X						20,000			X			–	–	X					X	–			NO FIRE
MAY 7				X						X				–	4	X				X		80			EN ROUTE
MAY 7		X						100,000			X			–	–	X				X		–			EN ROUTE
MAY 7	X							10,000	X					–	–	X						–			LOADING
MAY 7	X							8000	X					–	–	X					X	–			EN ROUTE
MAY 11				X				20,000			X			–	–	X				X		–			–
MAY 12	X									X				6	1	X				X		2,000			EN ROUTE – MULTIPLE COLLISION
MAY 13	X							3000	X					–	–	X						–			–
MAY 14				X				20,000			X			–	1	X				X		–			EN ROUTE
MAY 15				X						X				1	1	X				X		67			EN ROUTE
MAY 19	X							2000	X					–	–	X						–			–
MAY 23	X							75,000	X					–	–	X						–			–
JUNE 2, 1969	X							20,000			X			–	–			X			X	–			EN ROUTE
JUNE 2	X									X				3	–	X				X		100			LOADING/UNLOADING
JUNE 5	X							5000					X	–	–	X						–			–
JUNE 3	X							2000	X					–	–	X						–			–
JUNE 7	X							100,000					X	–	–	X						–			–
JUNE 9			X				5000		X					–	–	X						–			EN ROUTE
JUNE 10					X					X				2	1	X					X	16			EN ROUTE
JUNE 16	X							28,000	X					–	–	X						–			–

Table D-1-3
(Continued)

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
JUNE 23, 1969	X							64,000	X					–	–	X						–	PERIOD OF MOTOR CARRIER ACCIDENT SUMMARY PERIOD OF TANK CAR DERAILMENT SUMMARY	PERIOD OF OIL SPILL SUMMARY PERIOD OF HAZARDOUS MATERIAL SPILL SUMMARY	–
JUNE 23	X									X				–	5	X			X			75			EN ROUTE
			X							X						SMALL					X				
JUNE 29				X				120,000			X			–	–	X				X		–			EN ROUTE
JULY 7	X							3,000	X					–	–	X			X			–			JETTISONED EN ROUTE
JULY 9					X			300,000					X	–	–							–			50,000 FISH KILL
JULY 10	X							12,000,000	X					–	–							–			COLLISION
JULY 14	X							25,000					X	–	–							–			FLOOD WATERS
JULY 15	X							5,000	X					–	–	X					X	–			RAN AGROUND
JULY 16	X							1,000	X					–	–	X						–			LOADING
JULY 17					X			40,000			X			–	–		X			X		–			EN ROUTE
			X					100,000																	
JULY 18	X							1,000	X					–	–	X						–			JETTISONED
JULY 21	X							600,000	X					–	–	X			X			–			SINKING
JULY 23	X									X				–	–	X					X	21			UNLOADING
JULY 23	X										X			–			X			X		–			EN ROUTE
JULY 25					X						X			–			X			X		–			3½ MILE FISH KILL
AUGUST 2	X									X				–	1	X					X	27			EN ROUTE
AUGUST 3				X				20,000			X			1	–	X				X		–			EN ROUTE
AUGUST 14	X							6,000		X				–	–							–			EN ROUTE
AUGUST 18					X			5,000						–	–							–			EN ROUTE
AUGUST 22					X			LARGE					X	–	–	X					X	–			HURRICANE CAMILLE
AUGUST 25					X			LARGE					X	–	–	X			X			–			HURRICANE CAMILLE
SEPTEMBER 9			X					8,000					X	–	–	X						20			350,000 FISH KILL
SEPTEMBER 16	X							600,000	X					–	–	X					X	EXTENSIVE			RAN AGROUND
SEPTEMBER 26	X							3,000		X				–	–	X					X	–			EN ROUTE
SEPTEMBER 26	X							30,000					X	–	–			X			X	–			–
SEPTEMBER 29	X							40,000			X			–	–	X					X	–			EN ROUTE
OCTOBER 2	X							4,000	X					–	–	X						–			UNLOADING
OCTOBER 3					X									–	–							EXTENSIVE			750,000 FISH KILL
OCTOBER 7	X							50,000					X	–	–	HALF						PARTIAL			HANDLING
OCTOBER 9	X							2,000						–	–							–			–
OCTOBER 10	X							4,000					X	–		X				X					–

Table D-1-3
(Continued)

DATE	COMMODITY						QUANTITY		MODE					DEATH	INJURY	COMMODITY DAMAGE			EQUIPMENT DAMAGE			PROPERTY DAMAGE IN THOUSANDS OF DOLLARS			REMARKS
	FLAMMABLE MATERIALS	COMPRESSED GASES	CORROSIVE MATERIALS	EXPLOSIVES	POISONS	RADIOACTIVE MATERIALS	TONS	GALLONS	SHIP	TRUCK	RAILROAD	PIPELINE	STORAGE			TOTAL	EXTENSIVE	PARTIAL	TOTAL	EXTENSIVE	PARTIAL				
OCTOBER 14, 1968	X							4000	X					–	–	X					X	–	PERIOD OF OIL SPILL SUMMARY	PERIOD OF HAZARDOUS MATERIAL SPILL SUMMARY	COLLISION
OCTOBER 14	X								X					–	–			X			X	–			COLLISION
OCTOBER 16	X							3000		X				–	–						X	–			EN ROUTE
OCTOBER 17	X							20,000			X			–	–			X			X	–			EN ROUTE
			X					20,000										X			X	–			
NOVEMBER 5, 1968	X						800		X					–	–	NONE					X	–			COMMODITY RECOVERED
NOVEMBER 7	X							6500		X				–	–	X					X	EXTENSIVE			LARGE FISH KILL
NOVEMBER 13			X					4700						–	–							–			–
NOVEMBER 19		X								X				6	19	NONE					X	EXTENSIVE			EN ROUTE – PROPANE DID NOT ESCAPE/IGNITE
NOVEMBER 22			X					1000			X			–	–	X					X	–			EN ROUTE
NOVEMBER 24			X					40,000	X					–	–						X	–			RR CARS ON BARGE
NOVEMBER 25			X				200						X	–	–	X					X	–			–
NOVEMBER 27	X							3000				X		–	–	X					X	–			–
DECEMBER 8, 1968		X						20,000			X			–	2	X				X		MINOR			130 PERSONS EVACUATED
			X					20,000								X				X					
1968					X			20,000			X			–	–		X		MINOR			SOME			EXTENSIVE DAMAGE TO VEGETATION
1968					X			SMALL		X				–	1	SMALL						SOME			EN ROUTE
1968					X					X				–	1				SOME			SOME			EN ROUTE

REFERENCES

1. "An Appraisal of the Problem of Handling, Transportation, and Disposal of Toxic and Other Hazardous Materials," Prepared by Booz, Allen and Hamilton, Inc., Washington, D.C., January 1970.

Table D-2-1

Typical Hazardous Chemicals Distributed to Major Industrial Segments by SIC Code

20 Food & Kindred Prod.	22 Textile Mill Prod.	26 Paper & Allied Prod.	29 Petroleum & Coal Prod.	31 Leather & Leather Prod.	33 Primary Metal Ind.	34 Fabricated Metal Prod.
Acetic Anhydride Acetic Acid Acetyl Chloride Aluminum Fluoride Aluminum Sulfate Ammonium Chloride Ammonium Fluoride Ammonium Persulfate Amyl Acetate Boric Acid Carbon Monoxide Critric Acid Cresols Ethanol Ethylamine Hydrogen Peroxide Isopentane Magnesium Oxide Nitrous Oxide Potassium Fluoride Propylene Dichloride Sodium Bisulfite Sodium Nitrite Sorbitol Sulfur Dioxide Zinc Oxide	Acrylic Acid Acrylonitrile Ammonium Sulfate Ammonium Chromate Ammonium Fluoride Ammonium Sulfide Amyl Acetate Amyl Alcohol Antimony Boric Acid Butyl Acetate Diethylene Glycol Ehtanolamines Ethyl Acrylate Ethylenimine Formic Acid Isopropyl Ether Magnesium Sulfate Mercuric Chloride Oxalic Acid Pentachlorophenol Perchloroethylene Potassium Dichromate Sodium Arsenates Sodium Hydrosulfite Thiocyanates Trichloroethane Trichloroethylene Zinc Oxide	Acetic Anhydride Acrylic Acid Aluminum Sulfate Butyl Acetate Chlorine Dimethyl Sulfate Ethyl Acrylate Ethylenimine Hydrogen Peroxide Magnesium Oxide Magnesium Sulfate Mercury Pentachlorophenol Potassium Dichromate Sodium Bisulfite Sodium Carbonate Sodium Hydroxide Sodium Silicate Sulfur Dioxide Thiocyanates	Dimethyl Sulfate Dinitrocresols Ethanolamines Ethylene Bromide Hydrofluoric Acid Meta-p-Nitroaniline Methyl Methacrylate Nonylphenol Phosphorus Oxychloride Phosphorus Pentasulfide Potassium Dichromate Propane Propylene Sodium Hydroxide Strontium Sulfur Dioxide Tar Crude Tetraethyl Lead Thiocyanates Toluene Triethylene Glycol Tri-o-Cresyl Phosphate	Acrylic Acid Aluminum Sulfate Arsenic Trioxide Boric Acid Ethyl Acrylate Formic Acid Lead Acetate Magnesium Sulfate Mercuric Chloride Methyl Acrylate Oxalic Acid Potassium Dichromate	Acetylene Aluminum Fluoride Ammonium Sulfide Antimony Arsenic Barium Carbonate Boric Acid Boron Trichloride Boron Trifluoride Calcium Arsenate Carbon Monoxide Hydrocyanic Acid Hydrofluoric Acid Lead Lead Cyanide Mercuric Chloride Mercuric Sulfate Nickel Nickel Cyanide Nitric Acid Oxalic Acid Oxygen Potassium Cynide Selenium Sodium Sodium Borate Sodium Nitrite Sulfur Dioxide Sulfuric Acid Tantalum Thallium Trichloraethane Zinc Chloride	Acetylene Ammonium Sulfide Ammonium Persulfate Antimony Trichloride Boric Acid Cadmium Cadmium Salts Chromic Acid Cresol Hexamethylene Diamine Hydrocyanic Acid Hydrofluoric Acid Hydrogen Sulfide p - Hydroquinone Isobutyl Acetate Lead Cyanide Manganese Nickel Nickel Ammonium Sulfate Nickel Cyanide Nitric Acid Oxalic Potassium Cyanide Potassium Dichromate Silver Cyanide Sodium Nitrite Sulfuric Acid Thallium Thiocyanates Trichloroethane Trichloroethylene Vinyl Chloride Zinc Chloride